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Maraval et al.

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(54) **METHOD AND APPARATUS FOR CONTROLLING A LIFTING MAGNET SUPPLIED WITH AN AC SOURCE**

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(51) **Int. Cl.**
H01H 47/00 (2006.01)

(52) **U.S. Cl.** **361/144; 361/143; 361/152**

(58) **Field of Classification Search** **361/144**
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,445,105 A 5/1969 Marcher
3,859,571 A 1/1975 Strobl et al.
5,813,712 A * 9/1998 Mozelt 294/65.5
5,875,281 A 2/1999 Thexton et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CN 2920948 Y 7/2007

(Continued)

OTHER PUBLICATIONS

Fukada Takafumi, Method and apparatus for controlling voltage of lifting magnet, Publication date: Dec. 13, 2002, Drawing 4a, par. 0004.*

(Continued)

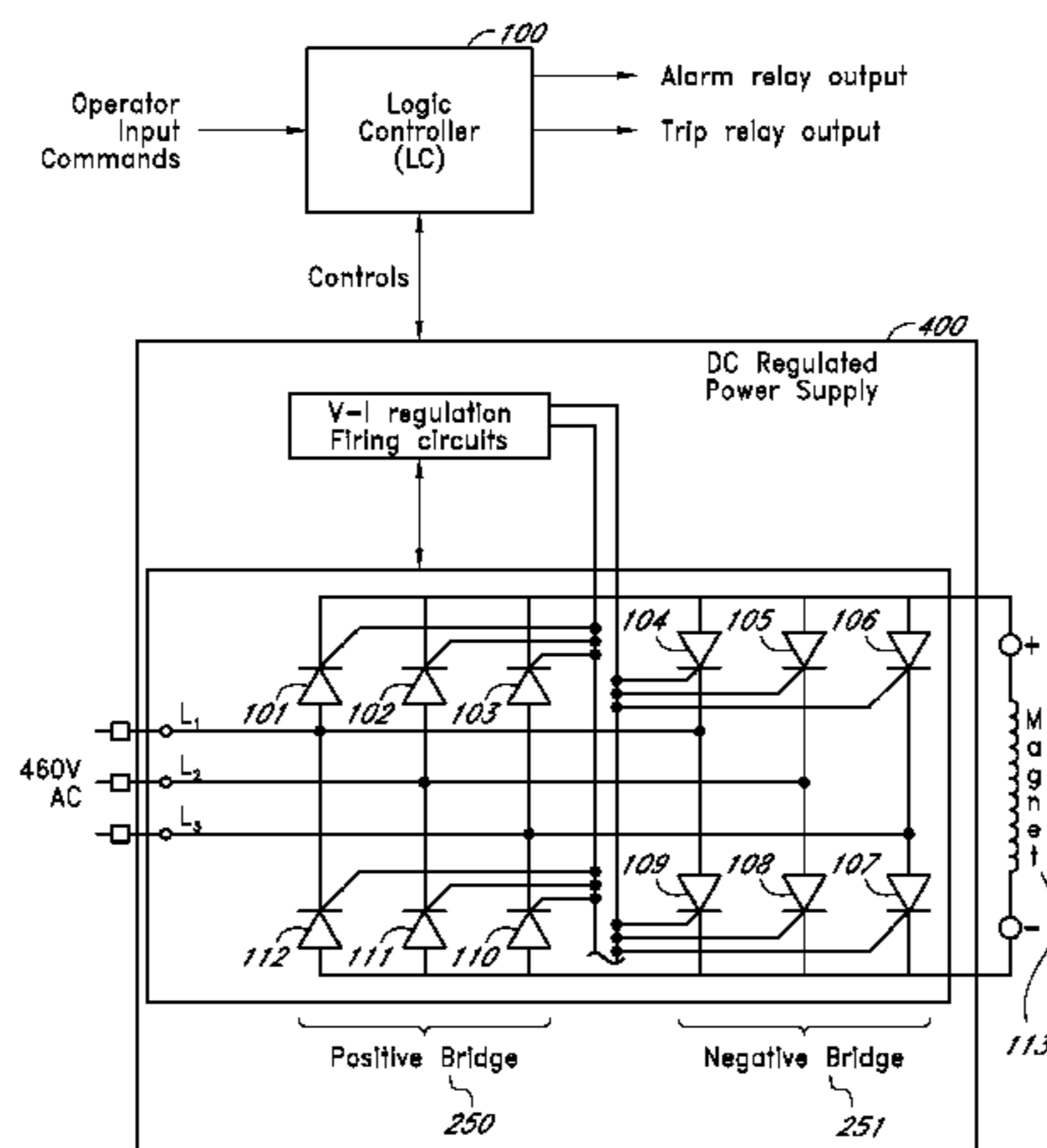
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(57) **ABSTRACT**

A magnet controller supplied by an AC source controls a lifting magnet. Two bridges allow DC current to flow in both directions in the lifting magnet. During “Lift”, relatively high voltage is applied to the lifting magnet until it reaches its cold current. Then voltage is lowered. After a desired interval, once the magnet has had time to build its electromagnetic field, voltage is further reduced to prevent the magnet from overheating. The magnet lifting force is maintained due to the magnetic circuit hysteresis. During “Drop”, reverse voltage is applied briefly to demagnetize the lifting magnet. At the end of the “Lift” and the “Drop”, most of the lifting magnet energy is returned to the line source. A logic controller controls current and voltage of the magnet and calculates the magnet’s temperature. In one embodiment, a “Sweep” switch is provided to allow reduction of the magnet power to prevent attraction to the bottom or walls of magnetic rail cars or containers.

15 Claims, 20 Drawing Sheets



US 8,004,814 B2

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U.S. PATENT DOCUMENTS

5,905,624 A * 5/1999 Andreica et al. 361/144
6,088,210 A 7/2000 Goodman
6,710,574 B2 3/2004 Davis et al.
7,461,569 B2 * 12/2008 Bianchi 74/335
7,495,879 B2 * 2/2009 Thexton et al. 361/144
7,697,253 B1 4/2010 Maraval
2005/0094345 A1 5/2005 Pollock et al.
2008/0143260 A1 6/2008 Tuymen et al.
2009/0160590 A1 6/2009 Maraval et al.
2009/0161284 A1 6/2009 Maraval

FOREIGN PATENT DOCUMENTS

DE 2610781 A1 9/1977
JP 05343222 A 12/1993

JP 09142770 A 6/1997
JP 2002359112 A 12/2002
JP 2004299821 A 10/2004
WO WO 2009/086171 7/2009

OTHER PUBLICATIONS

Notice of Allowance dated Dec. 2, 2009 from Related U.S. Appl. No. 11/757,304.
International Search Report from PCT/US2008/087785, Apr. 6, 2009, 5 pages.

* cited by examiner

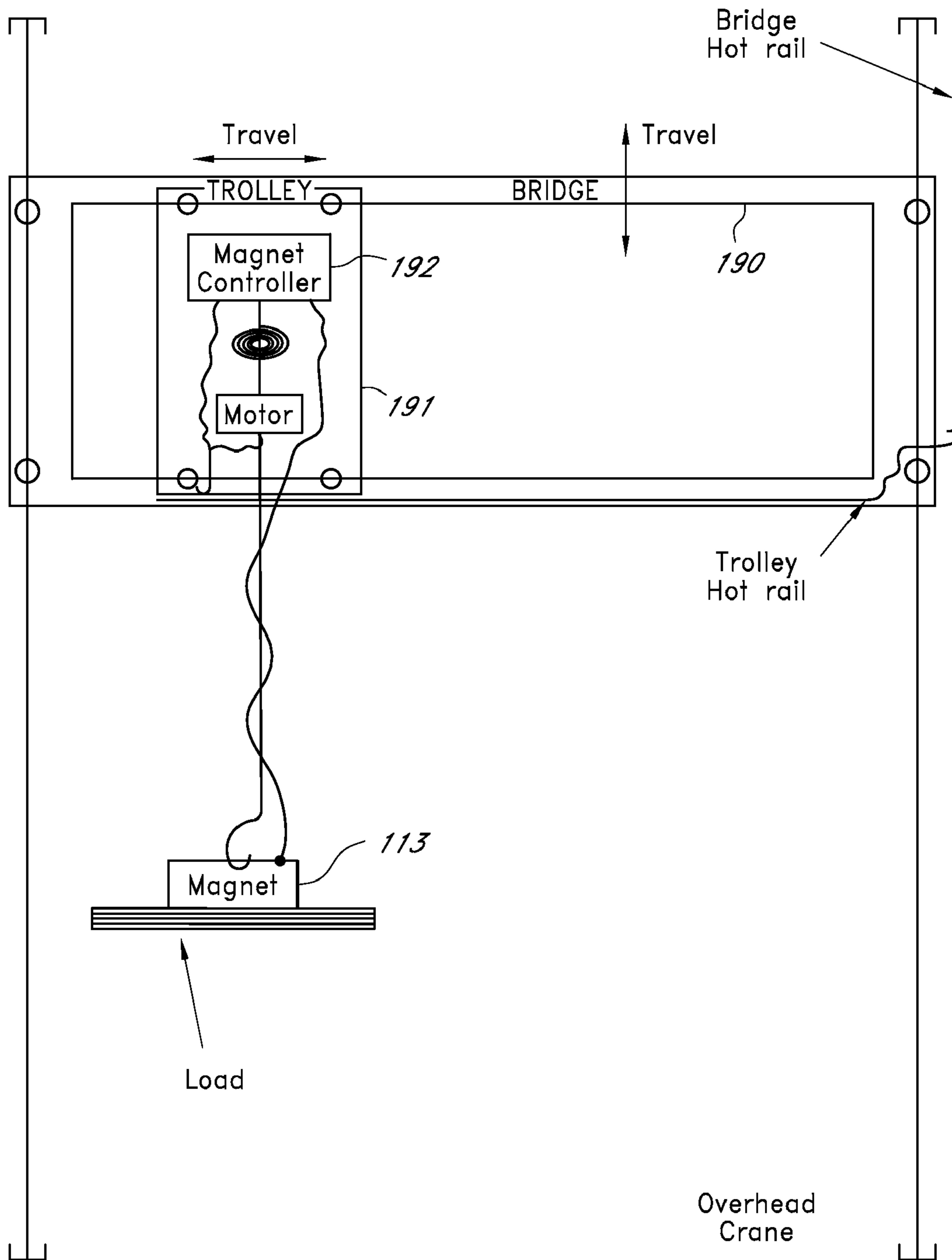


FIG. 1

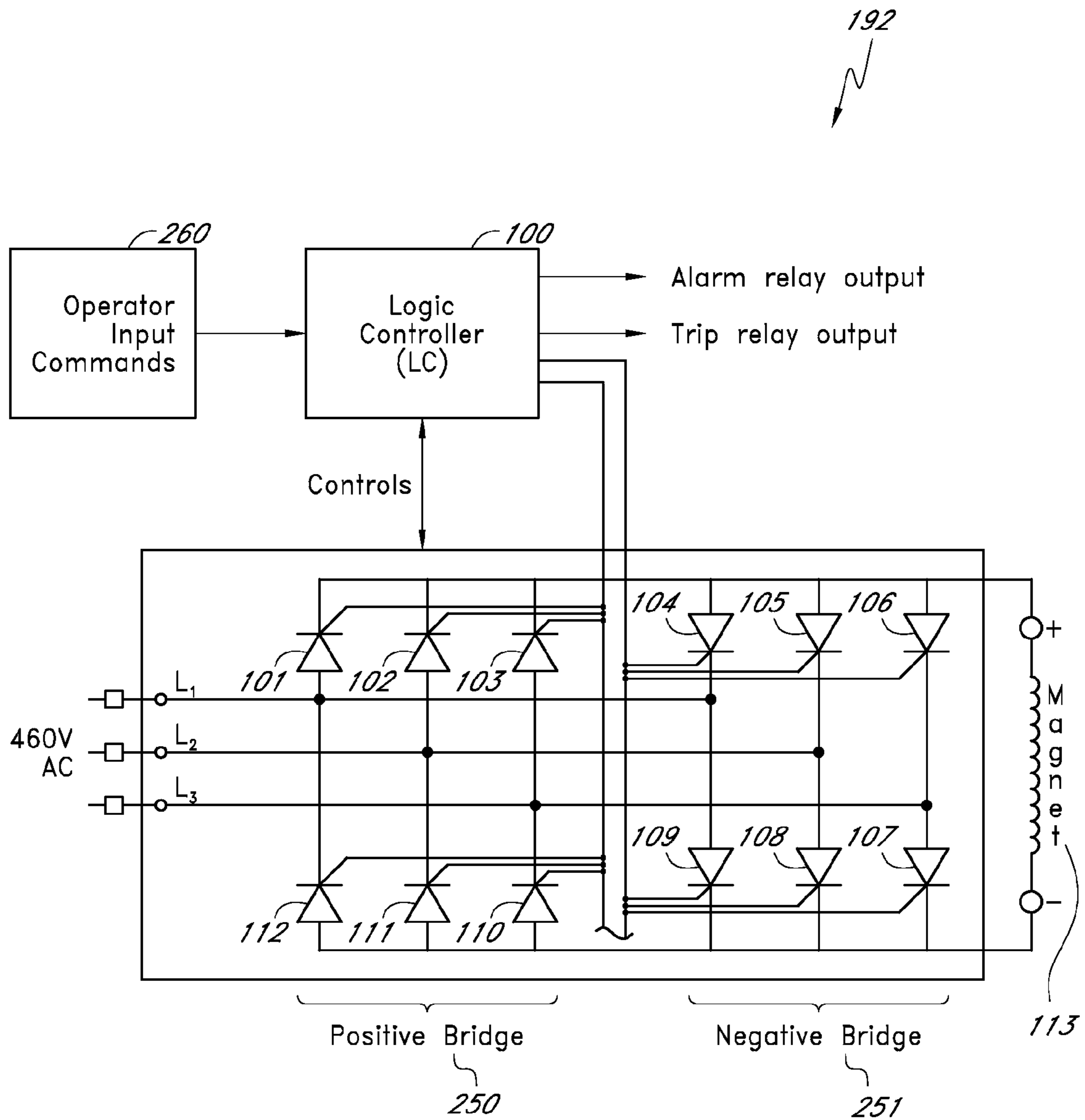


FIG. 2A

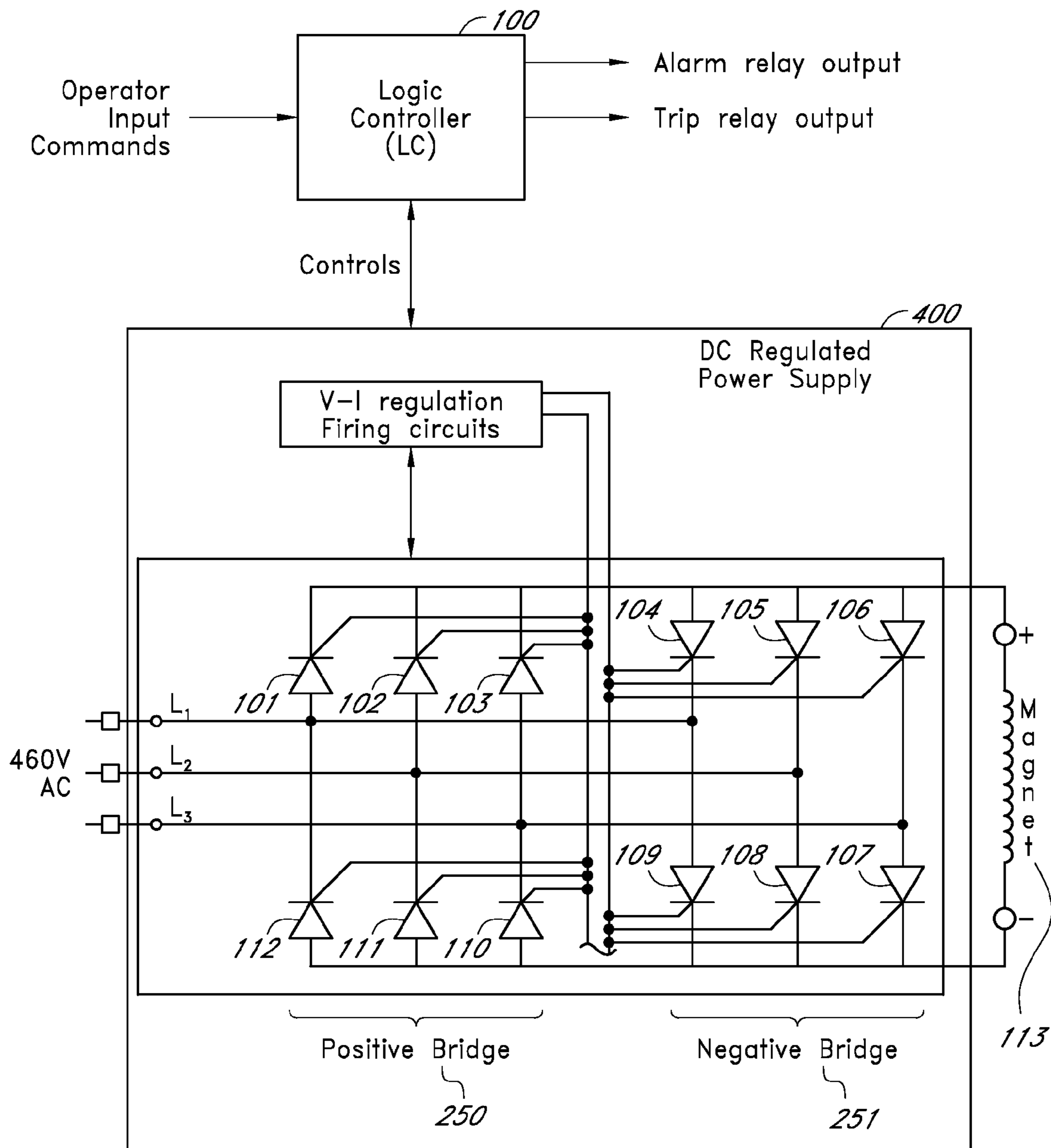


FIG. 2B

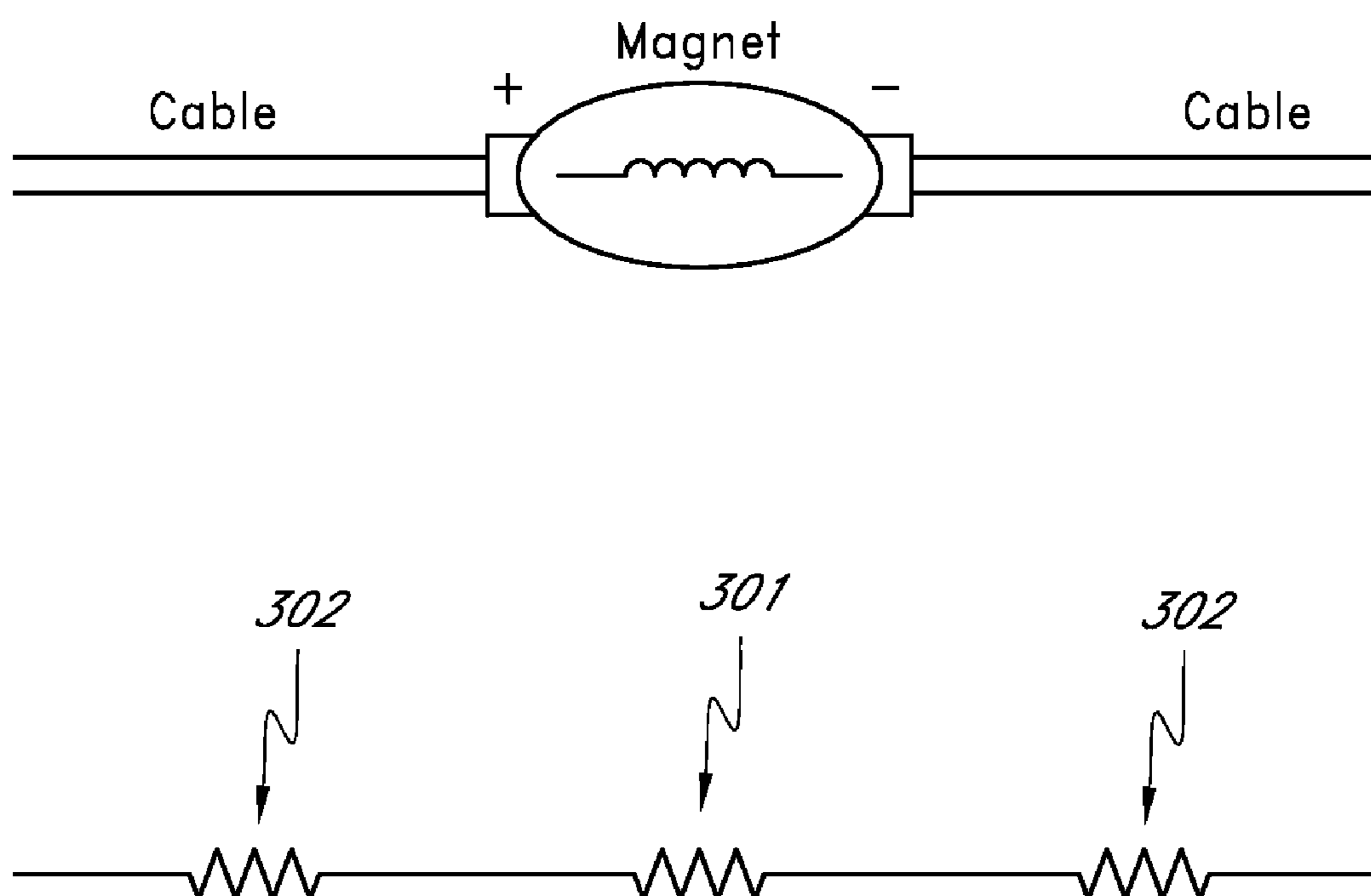
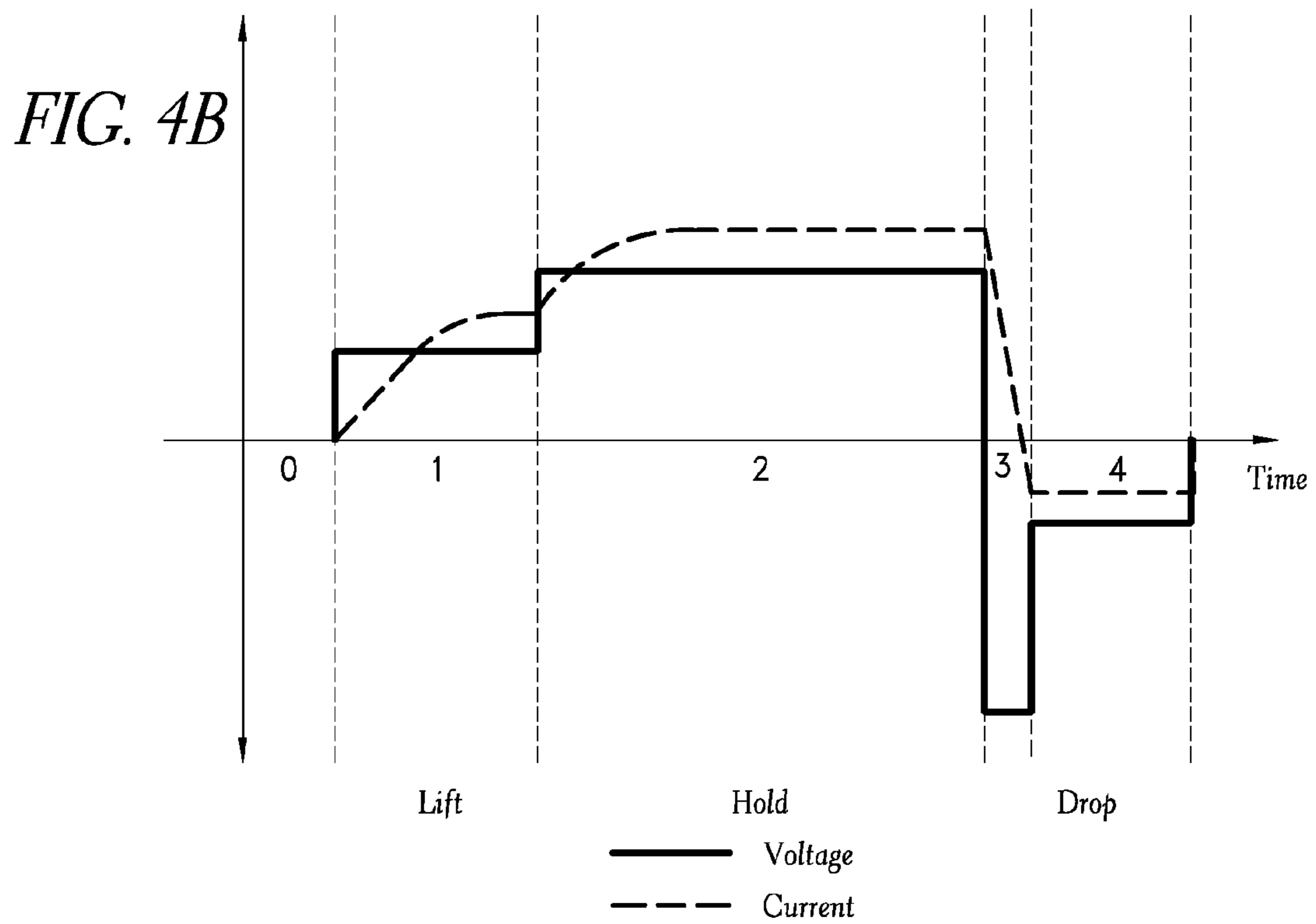
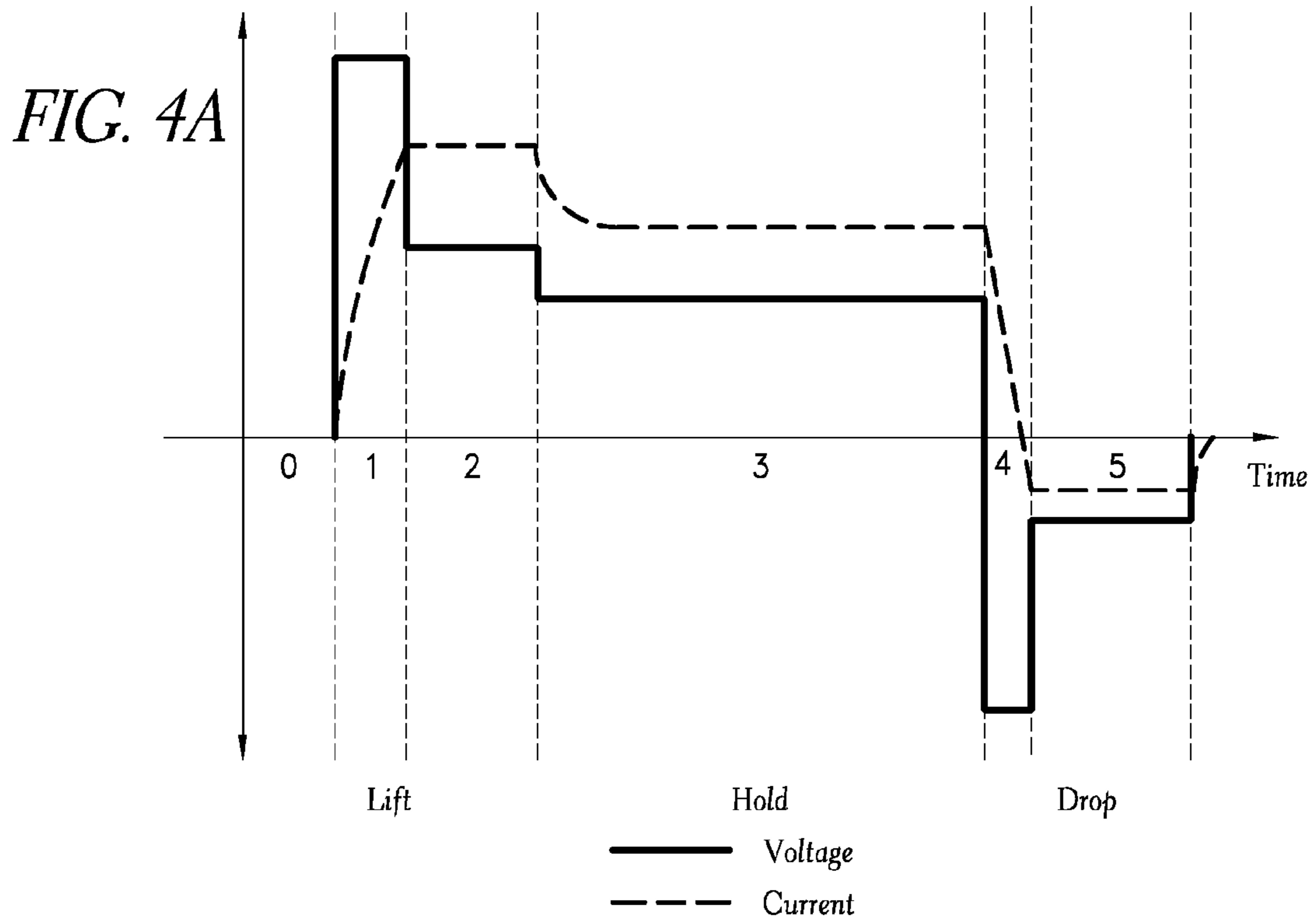


FIG. 3

DC Equivalent Circuit



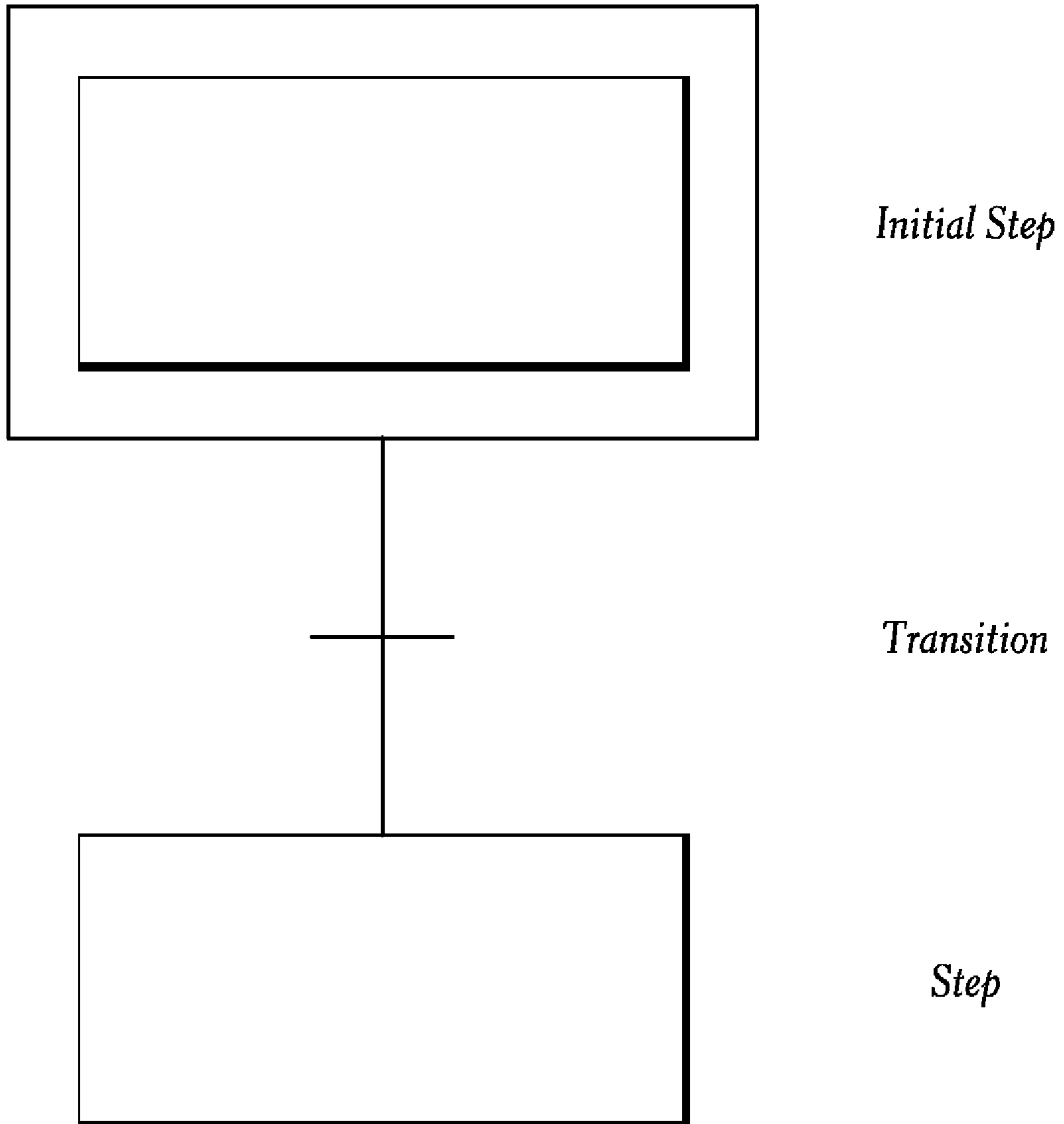


FIG. 5

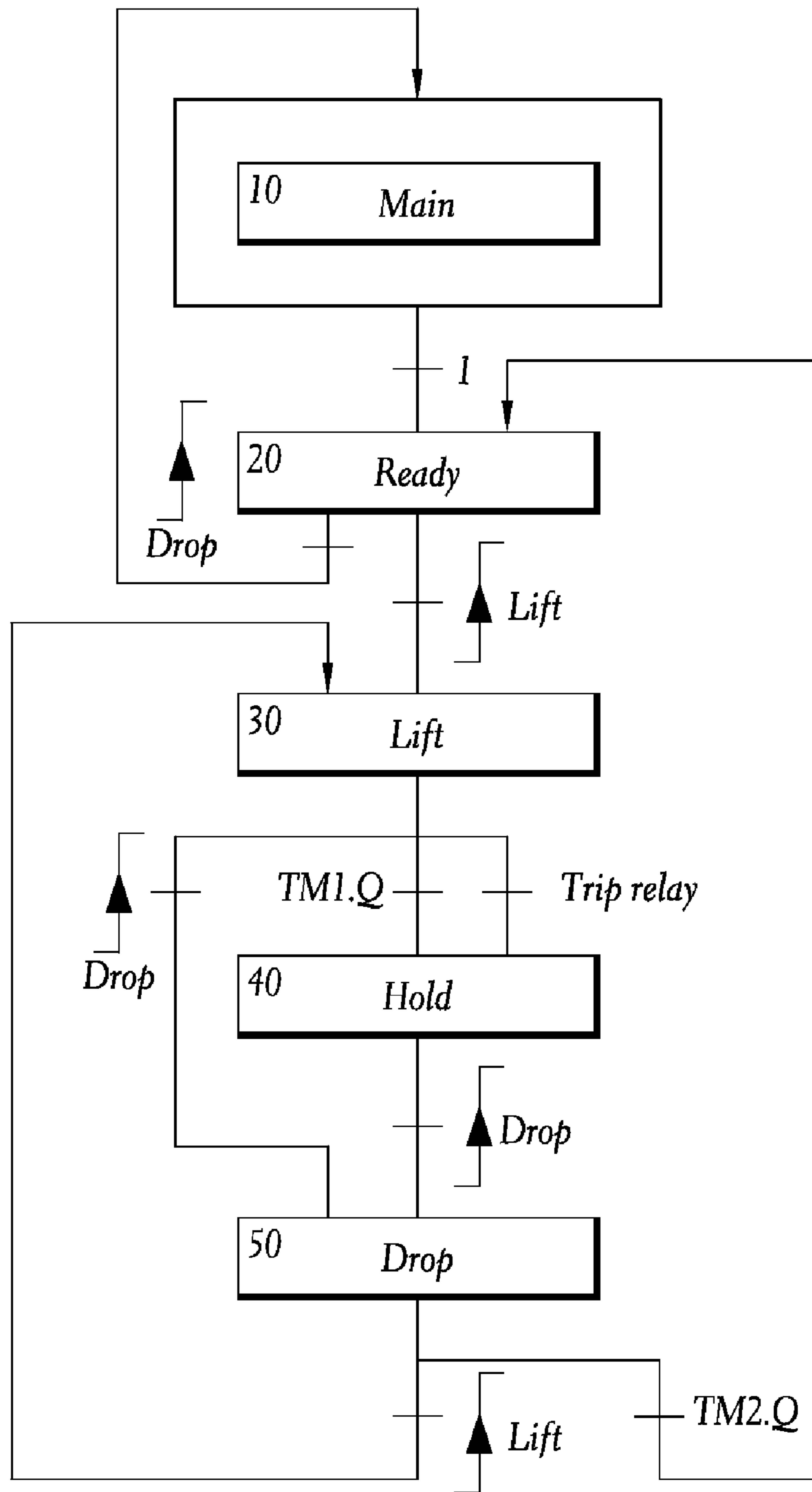


FIG. 6

Main SFC

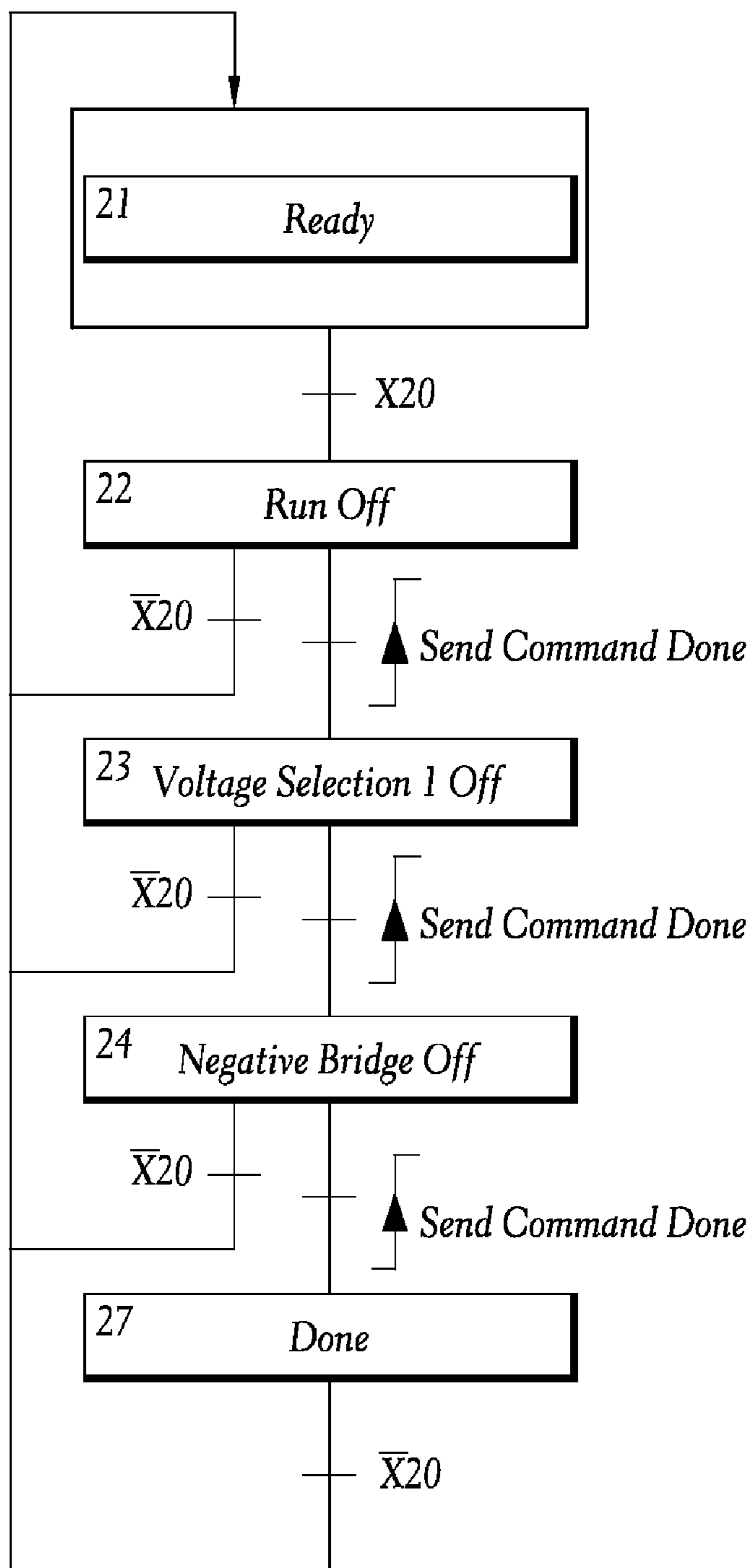


FIG. 7

Ready SFC

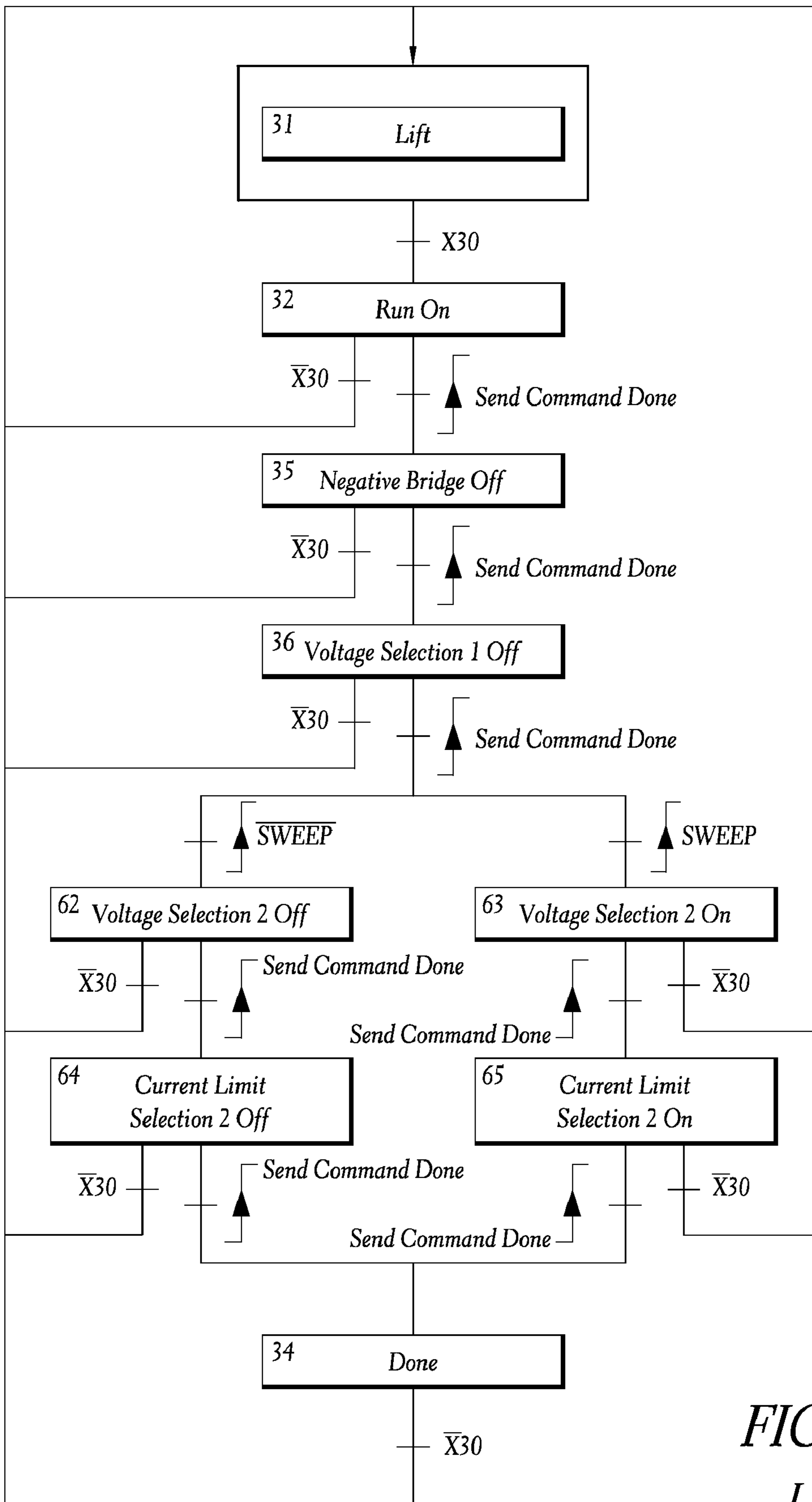


FIG. 8
Lift SFC

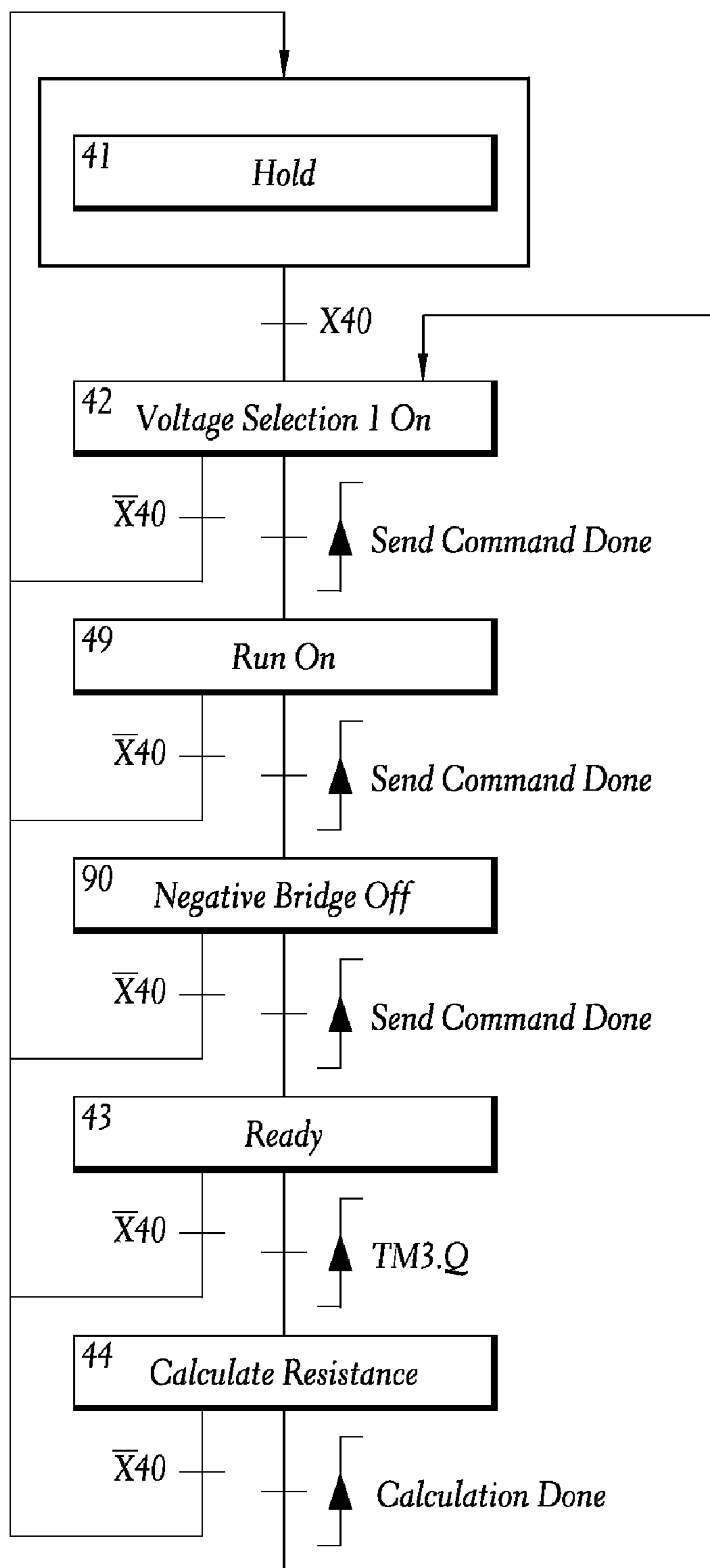


FIG. 9

Hold SFC

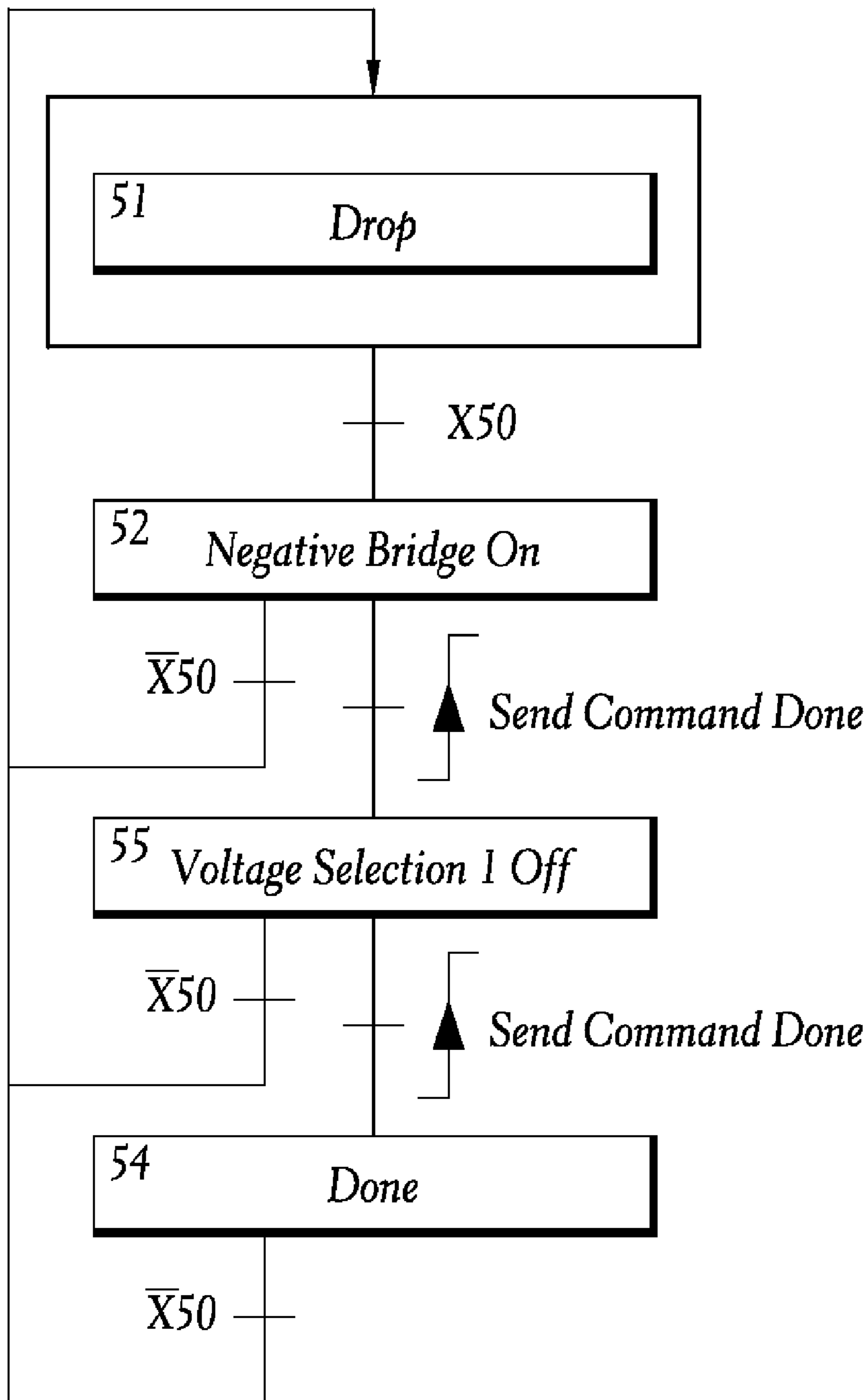


FIG. 10
Drop SFC

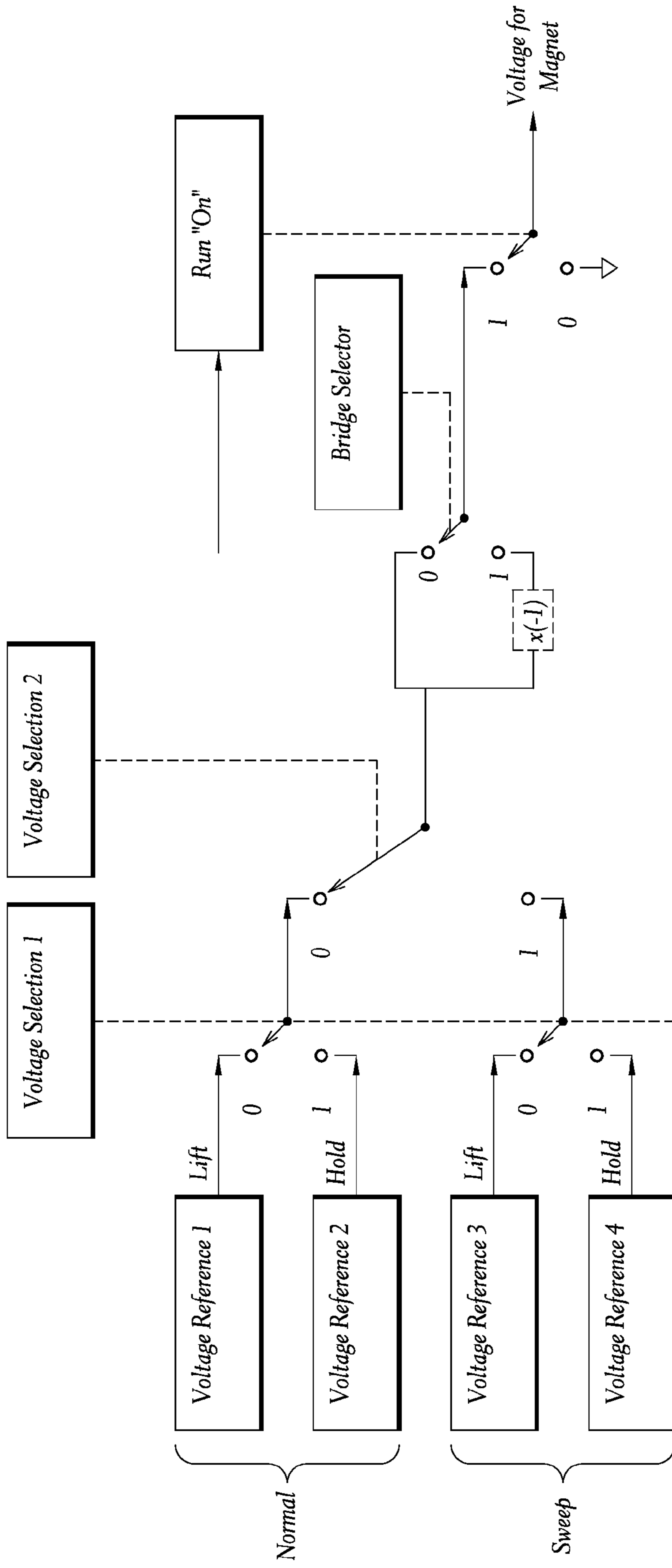


FIG. 11

DC Regulated Power Supply Voltage Selection

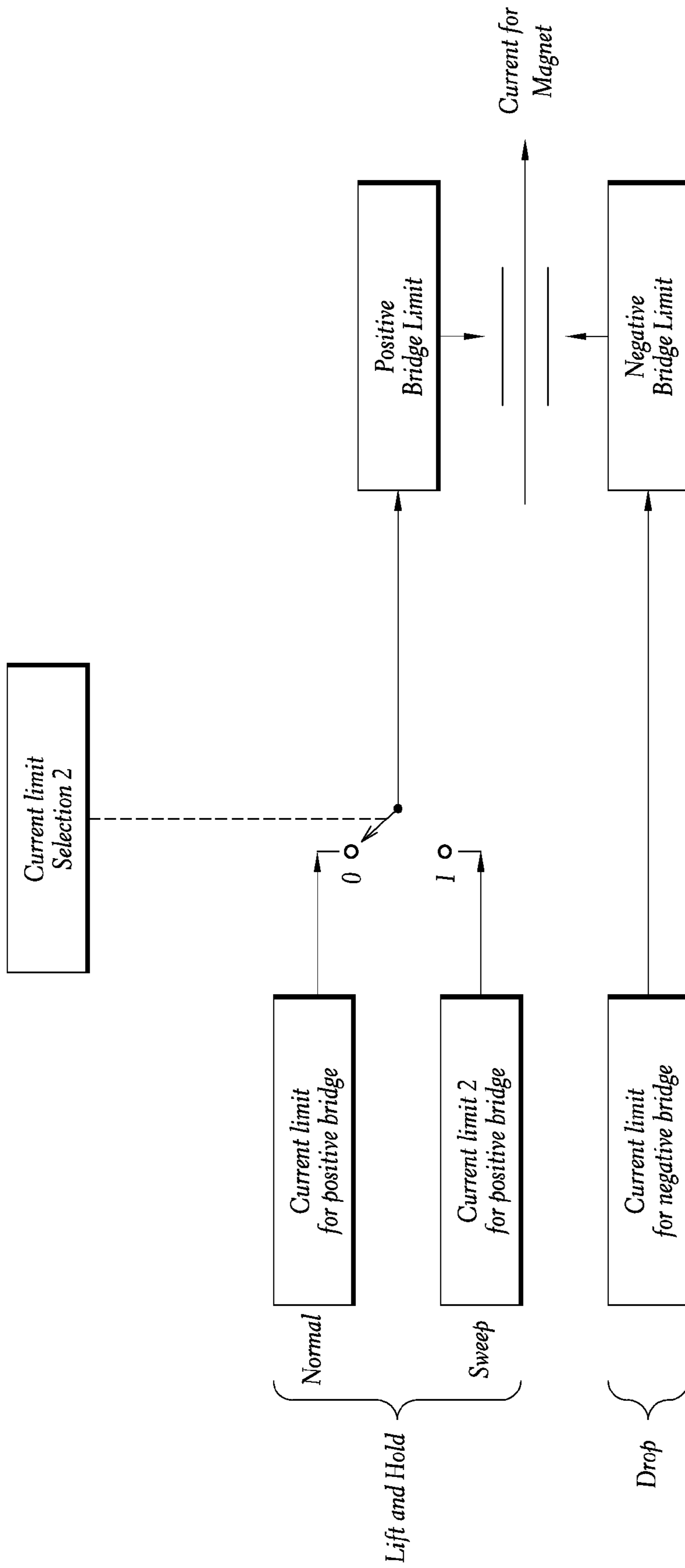


FIG. 12

DC Regulated Power Supply Current Selection

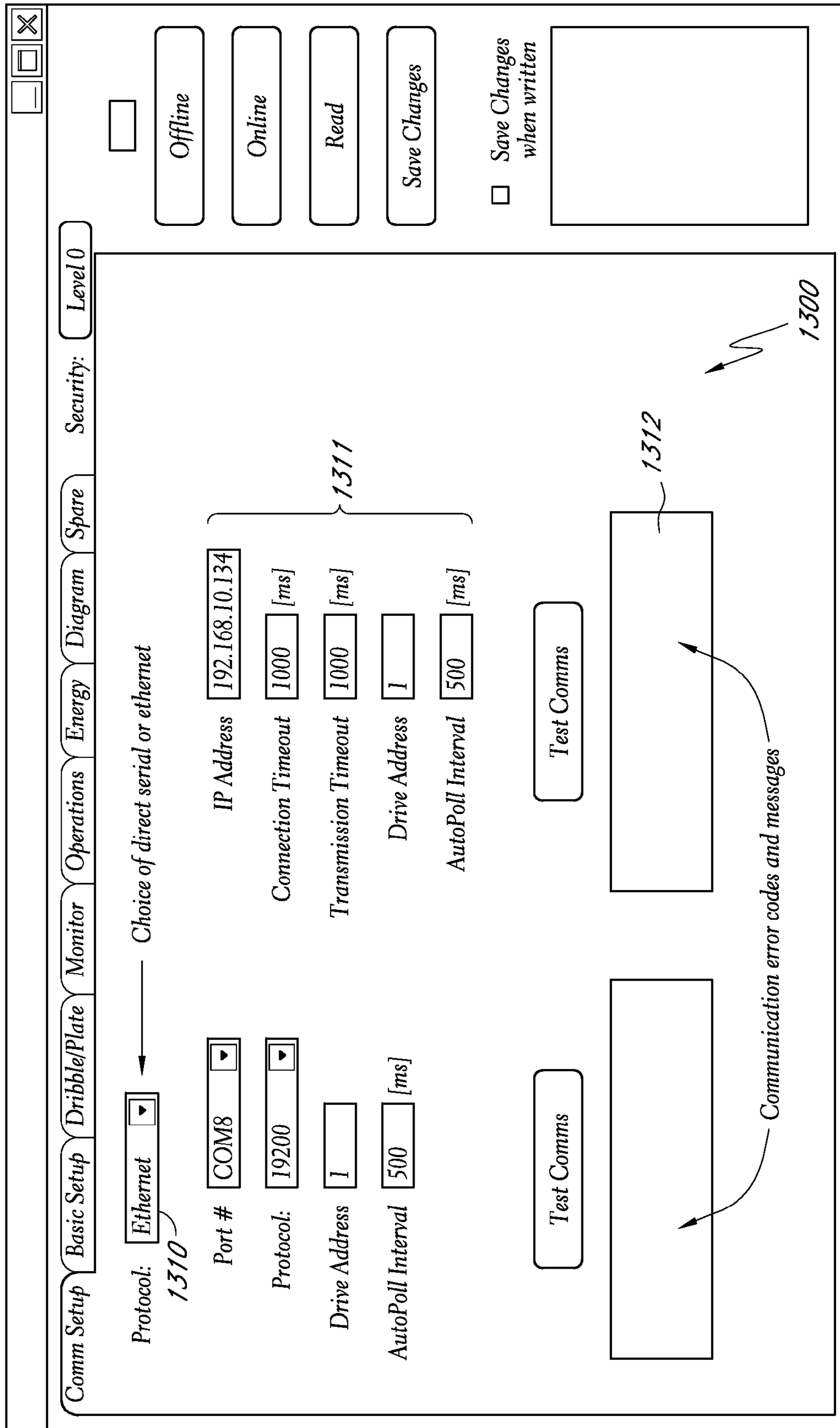


FIG. 13

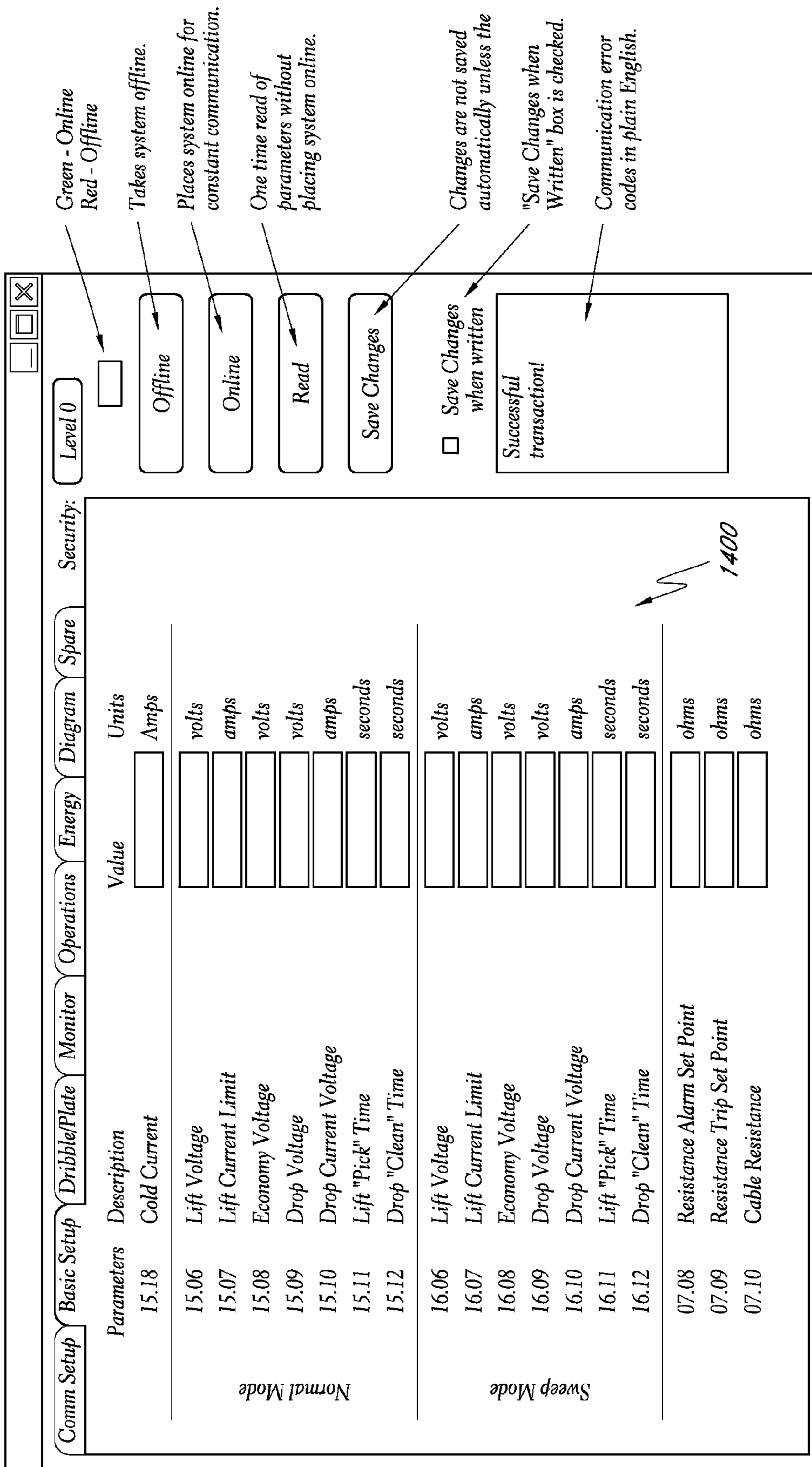


FIG. 14

Comm Setup
Basic Setup
Dribble/Plate
Monitor
Operations
Energy
Diagram
Spare
Security: Level 0

Parameters	Description	Value	Units
15.14	Dribble/Plate Option	<input type="text"/>	
15.16	Dribble Ramp Rate	<input type="text"/>	volts per second
15.19	Option 4,5, or 6 Voltage Adjust	<input type="text"/>	volts
15.20	Option 6 Voltage Adjustment Delay	<input type="text"/>	seconds
16.16	Option 6 Voltage Preset 1	<input type="text"/>	volts
16.17	Option 6 Voltage Preset 2	<input type="text"/>	volts
16.18	Option 6 Voltage Preset 3	<input type="text"/>	volts
16.19	Option 6 Voltage Preset 4	<input type="text"/>	volts
16.20	Option 6 Voltage Preset 5	<input type="text"/>	volts
16.21	Option 6 Bridge/Trolley Override	<input type="checkbox"/>	volts

Dribble

15.29 Potentiometer Adjusted Lift

15.08 Economy "Hold" Voltage

16.01 Potentiometer Adjusted Lift Voltage

Save Changes when written

Successful transaction!

1500

FIG. 15

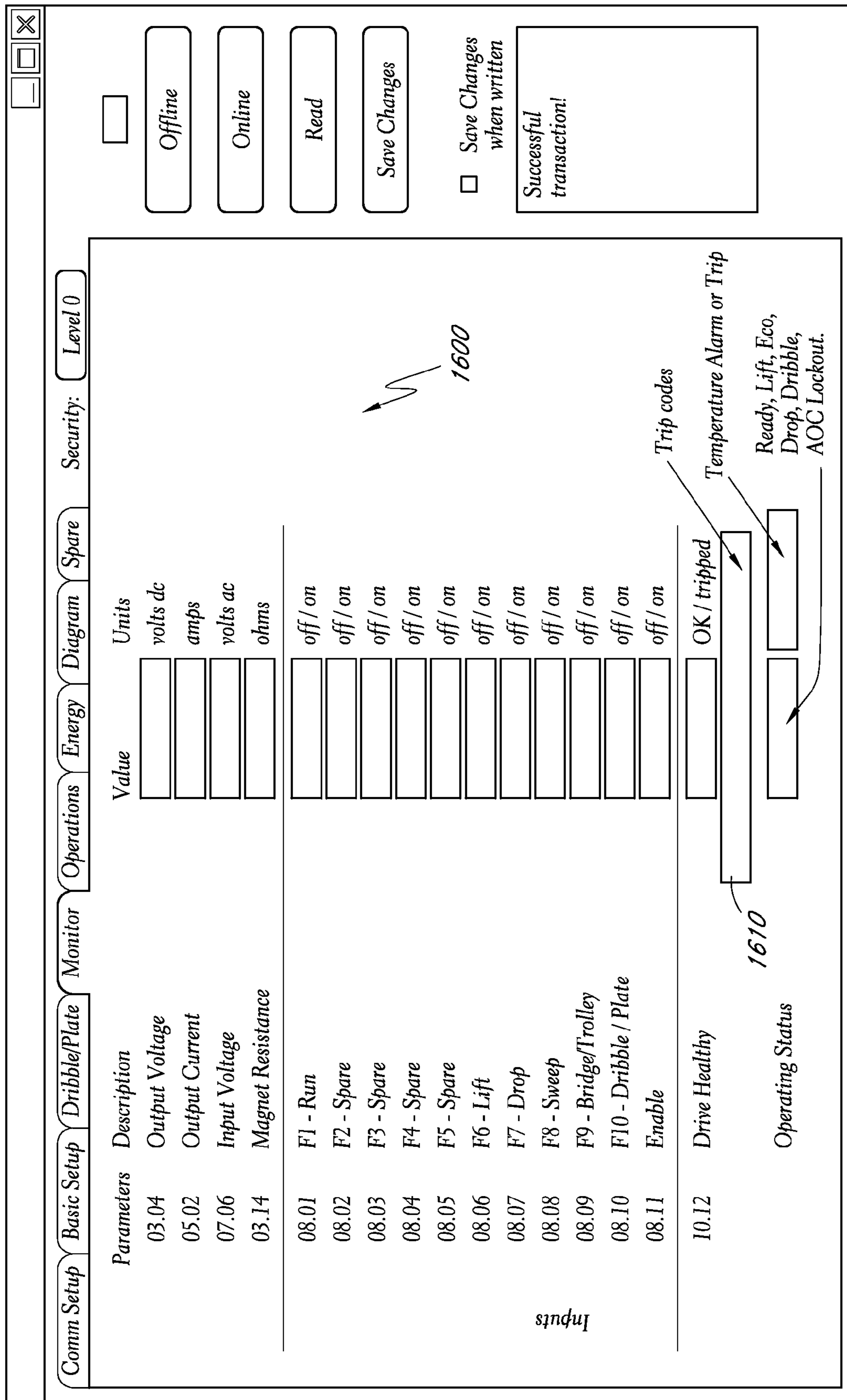


FIG. 16

Comm Setup
Basic Setup
Dribble/Plate
Monitor
Operations
Energy
Diagram
Spare
Security: Level 0

Parameters	Description	Value	Units
*	Total Operations		Normal + Sweep
*	Total Operation Time		hh.mm.ss Time of actual operation - Lift, Eco, Drop, Dribble.
*	Total Power-Up Time		hh.mm.ss
Normal Mode			
*	Operations		
*	Lift Time		hh.mm.ss
*	Economy Time		hh.mm.ss
*	Drop Time		hh.mm.ss
Sweep Mode			
*	Operations		
*	Lift Time		hh.mm.ss
*	Economy Time		hh.mm.ss
*	Drop Time		hh.mm.ss

1700

Resets counters only

Resets operation timers only

Resets only Power-Up timer

Save Changes when written

Successful transaction!

Offline
 Online
 Read
 Save Changes

FIG. 17

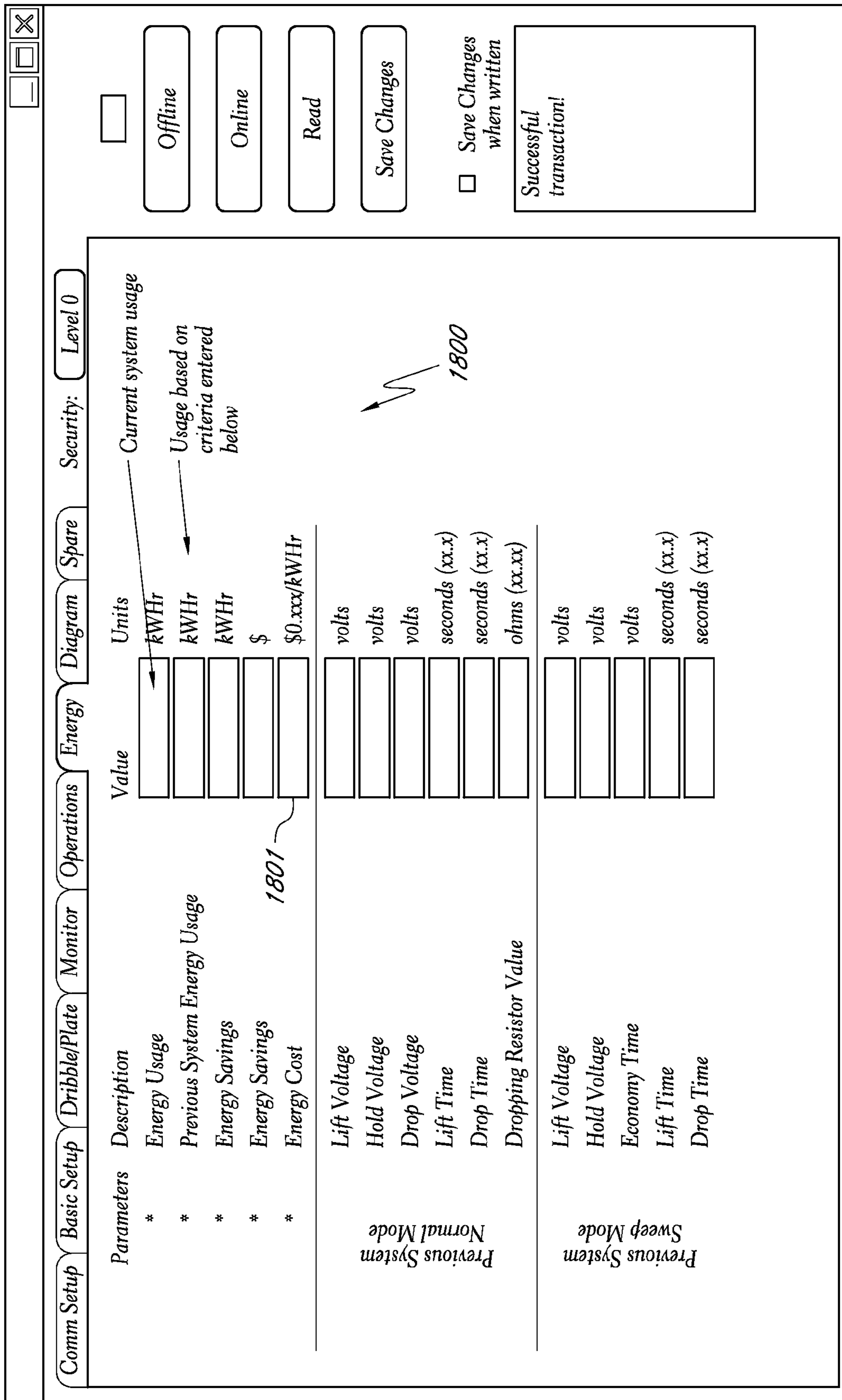


FIG. 18

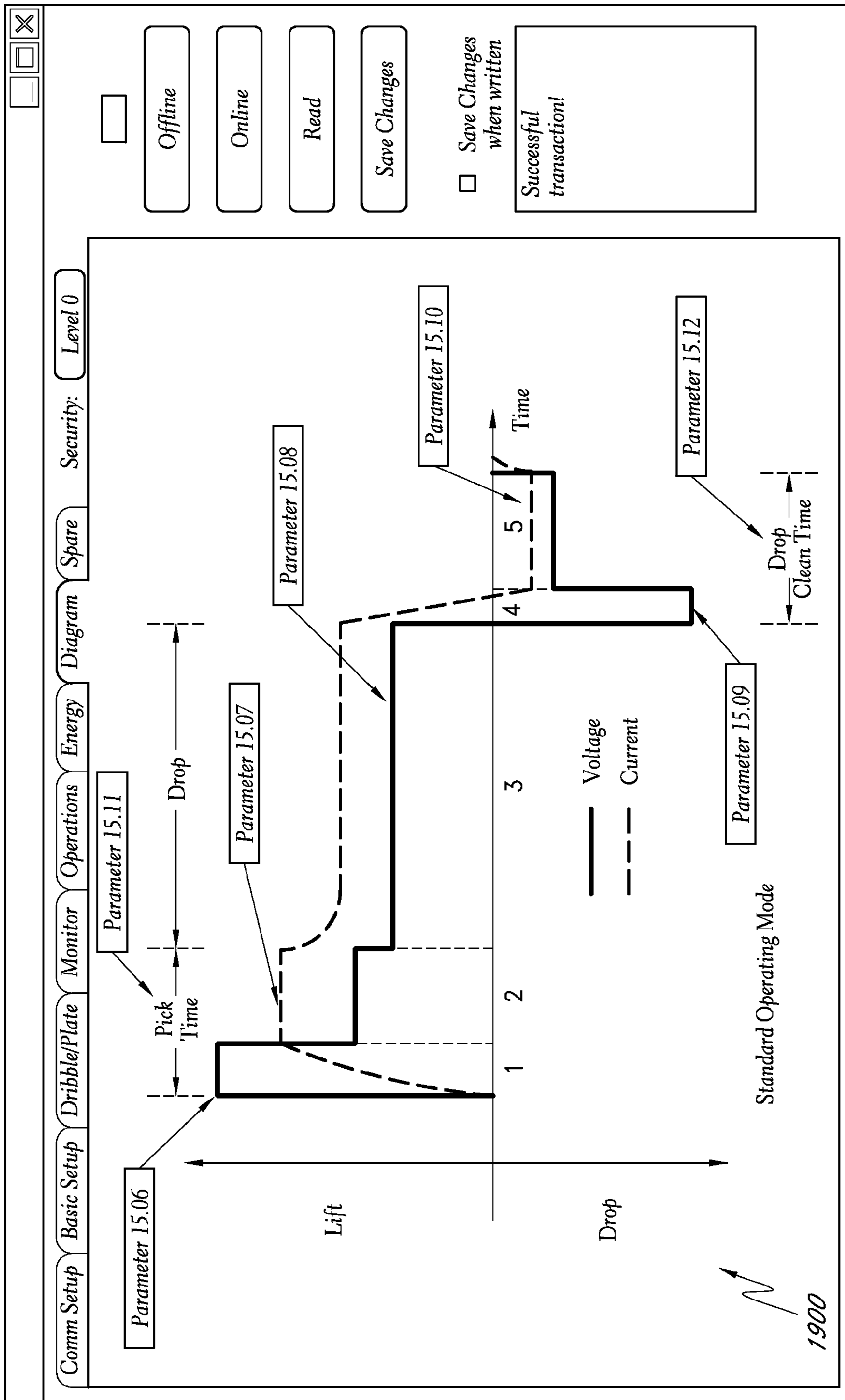


FIG. 19

1900

**METHOD AND APPARATUS FOR
CONTROLLING A LIFTING MAGNET
SUPPLIED WITH AN AC SOURCE**

REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of claims priority from U.S. Application No. 61/066,121, filed Dec. 19, 2007, titled "METHOD FOR CONTROLLING A LIFTING MAGNET SUPPLIED WITH AN AC SOURCE," and a continuation-in-part of claims priority from U.S. application Ser. No. 12/040,741, filed Feb. 29, 2008, titled "METHOD AND APPARATUS FOR CONTROLLING A LIFTING MAGNET SUPPLIED WITH AN AC SOURCE", the entire contents of which is hereby incorporated by reference.

BACKGROUND

1. Field of the Invention

The present invention relates to a method and apparatus for controlling a lifting magnet of a materials handling machine for which the source of electrical power is an AC power source.

2. Prior Art

Lifting magnets are commonly attached to hoists to load, unload, and otherwise move scrap steel and other ferrous metals. For many years, cranes were designed to be powered by DC sources, and therefore systems used to control lifting magnets were designed to be powered by DC as well. When using a hoist, due to the nature of the overhauling load, the torque and speed of the hoist motor need to be controlled. The traditional approach was to control the DC motor torque and speed by selecting resistors in series with the DC motor field and armature windings by means of contactors. In recent years, with the advance of electronic technology in the field of motor control, systems used to control lifting magnets, namely cranes, are now designed to be powered by AC sources. Cranes are now equipped with adjustable-frequency drives, commonly referred to as AC drives, which can accurately control the speed and torque of AC induction motors. The use of AC supplies removes the costs of installing and maintaining large AC-to-DC rectifiers, of replacing DC contactor tips, and of maintaining DC motor brushes and collectors. However, in order to use a lifting magnet on one of the new AC supplied cranes, a rectifier needs to be added to the crane. The rectifier that needs to be added to the crane is generally composed of a three-phase voltage step-down transformer connected to a six-diode bridge rectifier. The rectifier that is added to the crane is either mounted on the crane itself, where the rectifier becomes a weight constraint and an obstruction, or the rectifier is mounted elsewhere in the plant, in which case additional hot rails are required along the bridge and trolley in order for the DC electrical power to reach the DC-supplied magnet controller.

While lifting magnets have been in common use for many years, the systems used to control these lifting magnets remain relatively primitive. During the "Lift", a DC current energizes the lifting magnet in order to attract and retain the magnetic materials to be displaced. When the materials need to be separated from the lifting magnet, most of the controllers automatically apply a reversed voltage across the lifting magnet for a short period of time to allow the consequently reversed current to reach a fraction of the "Lift" current. The phase during which there is a reversed voltage applied across the magnet is known as the "Drop" phase, during which a magnetic field in the lifting magnet of the same magnitude but in an opposite direction of the residual magnetic field is

produced such that the two fields cancel each other. When the lifting magnet is free of residual magnetic field, the scrap metal detaches freely from the lifting magnet. This metal detachment is known as a "Clean Drop".

Some control systems operate to selectively open and close contacts that, when closed, complete a "Lift" or "Drop" circuit between the DC generator and the lifting magnet. At the end of the "Lift", which is called the "discharge" and at the end of the "Drop", which is called the "secondary discharge", these systems generally use either a resistor or a varistor to discharge the lifting magnet's energy. The higher the resistor's resistance value or varistor breakdown voltage, the faster the lifting magnet discharges, but also the higher the voltage spike across the lifting magnet. High voltage spikes cause arcing between the contacts. In addition, fast rising voltage spikes also eventually wear out the lifting magnet insulation, and the insulation of the cables connecting the lifting magnet to the controller. To withstand these voltage spikes, generally in the magnitude of 750 V DC with systems using DC magnets rated at 240 V DC, the lifting magnet, cables, and the control system contacts and other components need to be constructed of more expensive materials, and also need to be made larger in size.

Lifting magnets are rated by their cold current (current through the magnet under rated voltage, typically 250V DC, when the magnet temperature is 25° C.). These lifting magnets are designed for a 75% duty cycle (in a 10 minute period the magnet can have voltage applied at 250V DC for 7 minutes 30 seconds and the remaining 2 minutes 30 seconds the magnet must be off for cooling or the magnet will overheat). Today, magnet control systems are limited by the rectified DC voltage supplying the magnet control (typically 250-350V DC). These systems control the voltage to the magnet and as the magnet heats up, the resistance rises and the current drops. As a magnet heats up, the magnet loses 25-35% in lifting capacity because the resistance of the wire increases and the current through the lifting magnet decreases.

SUMMARY

These and other problems are solved by a new and improved method and apparatus for controlling a lifting magnet using an AC source, described here.

In one embodiment, the voltage and the current are controlled during the charging of the lifting magnet during the lift cycle. Charging involves the phase that begins the "Lift" mode during which the current in the lifting magnet increases. Voltage levels up to 500V DC or more are applied to the lifting magnet during the charge. When a current value related to the cold current rating of the lifting magnet is reached, the current is limited to this value until the end of the "Lift" mode. The lifting magnet can overheat if the current is maintained at the cold current level or higher, so after a preset time, during which the material attaches to the lifting magnet, the voltage on the lifting magnet is reduced to a holding voltage which causes a relatively lower current than the current applied during the "Lift" of the lifting magnet. The period during which there is a holding voltage applied to the lifting magnet is the "Hold" mode and this "Hold" mode allows the lifting magnet to hold the material that the lifting magnet has already picked-up.

In one embodiment, the "Lift" mode is initiated by the operator. During the "Lift" mode, a first voltage is applied across the lifting magnet. Then, the operator can select a relatively higher voltage to continue to be applied to the magnet in order to secure a load that has been picked up by the magnet.

In one embodiment, the voltage levels during “Lift” and “Hold” modes are user-selectable.

In one embodiment, the ratio of “Lift” to “Hold” voltages is user-selectable, based on the type of application sought.

In one embodiment, the magnetic field is maintained in the lifting magnet from the magnet’s cold state to the magnet’s hot state during the charging of the lifting magnet. Since the lifting magnet’s field is primarily controlled by NI (where N =turns of wire and I =current), maintaining the same current for a cold or hot magnet maintains substantially the same magnetic field.

In one embodiment, most of the lifting magnet energy used during the “Lift” and the “Drop” phases is returned to the line source rather than being dissipated in resistors, varistors, or other lossy elements.

In one embodiment, if during “Lift” or “Drop”, the controller is accidentally disconnected from the line, such that the current cannot keep flowing in the lifting magnet, the voltage across the lifting magnet sharply rises and consequently this fast voltage rise turns one or more voltage protection devices before their breakover voltage is attained. In addition, the lifting magnet controller circuitry can be protected by the use of circuit breakers, such as, for example, a high speed breaker.

In one embodiment, switching of current for the lifting magnet is provided by solid-state devices.

In one embodiment, the control system is configured to increase the useful life of the lifting magnet by reducing voltage spikes in the lifting magnet circuit. During operation, the instantaneous voltage across the magnet typically should not exceed the line voltage, i.e., for a system rated 460 V AC RMS, peak voltage is $460 \times \sqrt{2} = 650$ V, whereas voltages in prior art systems typically exceed 750 V.

In one embodiment, the control system is configured to increase the useful life of the lifting magnet, by providing a “Hold” mode that reduces magnet heating.

In one embodiment, the control system is configured to save energy by providing a “Hold” mode that reduces energy consumption.

In one embodiment, the control system is configured to reduce the “Lift” time. A shorter “Lift” time helps to increase production by reducing the lifting magnet cycle times. Using a higher AC voltage can provide relatively shorter “Lift” times. Some existing systems use a step-down voltage transformer which reduces the maximum voltage that can be applied to the magnet during “Lift”, and therefore these systems could not lift as quickly as systems with full line AC voltages.

In one embodiment, the control system is configured to reduce the “Drop” time. A shorter “Drop” time helps to increase production by reducing the lifting magnet cycle times. Some existing systems use a resistor, which causes voltage to decay with the current, leading to longer discharge times. Using a constant voltage source to discharge the lifting magnet energy allows a faster discharge.

In one embodiment, the control system is configured to monitor the lifting magnet resistance. Using the direct relationship between the magnet resistance and the magnet’s winding temperature, resistance values corresponding to different meaningful temperature levels of the lifting magnet can be monitored.

In one embodiment, the control system is configured to indicate an alarm to the operator if the lifting magnet temperature rises above a threshold level.

In one embodiment, the control system is configured to protect and increase the useful life of the lifting magnet by providing a “Trip” mode, which, based on an indication of the

lifting magnet’s temperature, determines whether the system should directly enter “Drop” mode instead of “Lift” mode, to reduce magnet heating.

In one embodiment, the control system is configured to prevent the lifting magnet from sticking to the bottom and walls of magnetizable containers by providing a “Sweep” mode that reduces the voltage levels applied to the lifting magnet during the “Lift” and “Hold” modes.

In one embodiment, a user console allow the user to specify operating parameters and to view calculations of energy usage and energy saved.

BRIEF DESCRIPTION OF THE DRAWINGS

- FIG. 1 shows an overhead crane with lifting magnet.
 FIG. 2A shows an AC lifting magnet system.
 FIG. 2B shows an AC lifting magnet system with an optional DC Power Converter such as a DC Regulated Power Supply.
 FIG. 3 illustrates an equivalent circuit for magnet resistance calculation.
 FIG. 4A shows voltage and current signals as the AC magnet controller is operated through “Lift”, “Hold” and “Drop” modes for handling scrap material, for example.
 FIG. 4B shows voltage and current signals as the AC magnet controller is operated through “Lift”, “Hold” and “Drop” modes for handling plates or slabs, for example.
 FIG. 5 shows a general Sequential Function Chart (SFC).
 FIG. 6 shows a flowchart for the Main SFC.
 FIG. 7 shows a flowchart for the Ready SFC.
 FIG. 8 shows a flowchart for the Lift SFC.
 FIG. 9 shows a flowchart for the Hold SFC.
 FIG. 10 shows a flowchart for the Drop SFC.
 FIG. 11 shows one embodiment of the DC Regulated Power Supply Voltage Selection.
 FIG. 12 shows one embodiment of the DC Regulated Power Supply Current Selection.
 FIG. 13 shows a communication setup page for user control of the lifting magnet system.
 FIG. 14 shows a first parameter setup page for user control of the lifting magnet system.
 FIG. 15 shows a second parameter setup page for user control of the lifting magnet system.
 FIG. 16 shows a monitor page for user control of the lifting magnet system.
 FIG. 17 shows an operations page for user control of the lifting magnet system.
 FIG. 18 shows an energy computation page for user control of the lifting magnet system.
 FIG. 19 shows a parameter diagram for user control of the lifting magnet system.

DETAILED DESCRIPTION

FIG. 1 shows an overhead crane with a bridge **190** provided to a trolley **191**. The trolley **191** is provided to a lifting magnet **113** controlled by a magnet controller **192**. The lifting magnet **113** is attached by cables to the magnet controller **192** which controls the lifting magnet **113**. The lifting magnet **113** is used to lift ferromagnetic materials such as, for example, one or more steel plates, steel girders, scrap steel, etc.

FIG. 2 shows a lifting magnet controller circuit **192** that includes a Logic Controller (LC) **100**. In one embodiment, the LC **100** can be a Programmable Logic Controller (PLC). The LC **100** receives input commands from an operator console **260** and provides alarm and trip relay outputs. The operator console **260** can be configured as a computer with a

display and human interface devices (e.g., mouse, keyboard, touchscreen, etc.). Outputs from the logic controller **100** are provided to respective switches **101-112**. The switches **101-103** and **110-112** are configured in a positive bridge **250** to provide current to the lifting magnet **113** in a first direction, and switches **104-109** are configured in a negative bridge **251** to provide current to the lifting magnet **113** in a second direction. The switches **101-112** can be any type of mechanical or solid-state switch device so long as the devices are capable of switching at a desired speed and can withstand voltage spikes. For convenience, and not by way of limitation, FIG. **2** shows the switches **101-112** as thyristors, each having an anode, a cathode and a gate. One of ordinary skill in the art will recognize that the switches **101-112** can be bipolar transistors, insulated gate bipolar transistors, field-effect transistors, MOSFETs, etc. One of ordinary skill in the art will also recognize that the number of switches used can be less or more than the twelve shown; using a greater number of switches reduces ripple.

FIG. **2A** shows the lifting magnet controller. FIG. **2B** shows one embodiment of the lifting magnet controller where a DC Power Converter such as a DC Regulated Power Supply **400** is used. The DC Regulated Power Supply **400** is one embodiment of a DC Power Converter, and is used as an example and not by way of limitation.

In FIGS. **2A** and **2B**, the thyristors **101-112** will initially conduct when the anode is positive with respect to the cathode and a positive gate current or gate pulse is present. The gate current can be removed once the thyristor has switched on. The thyristors **101-112** will continue to conduct as long as the respective anode remains sufficiently positive with respect to the respective cathode to allow sufficient holding current to flow. The thyristors **101-112** will switch off when the respective anode is no longer positive with respect to the respective cathode. The amount of rectified DC voltage can be controlled by timing the input to the respective gate. Applying current on the gate without delay to the natural commutation time will result in a higher average voltage applied to the lifting magnet **113** (where natural commutation time is understood in the art to be the time at which the SCRs would start conducting if they were replaced by diodes). Applying current on the gate later will result in a lower average voltage applied to the lifting magnet **113**. When the current in the magnet needs to be turned off, the application of the current on the gate can be further delayed to the point where voltage across the magnet **113** reverses, restoring the magnet energy to the AC supply. The period of time which precedes the “Drop” mode is called discharge. Six thyristors, **101-103** and **110-112**, are connected together to make a three-phase bridge rectifier **250**. The gating angle of the thyristors in relationship to the AC supply voltage determines how much rectified voltage is available. Converted DC voltage (V_{DC}) is equal to 1.35 times the RMS value of input voltage (V_{RMS}) times the cosine of the phase angle ($\cos \alpha$): $V_{DC} = 1.35 \times V_{RMS} \times \cos \alpha$. The value of the DC voltage that can be obtained from a 460 V AC input is thus $-621V$ DC to $+621V$ DC. The addition of the second, negative bridge **251** (i.e., connected in reverse with respect to the first positive bridge **250**) in the circuit allows for four-quadrant operation. The positive bridge **250** charges the lifting magnet **113** during the “Lift” mode and returns energy from the lifting magnet **113** back to the AC input during discharge. This four-quadrant circuit can also be used to demagnetize the lifting magnet **113** by applying voltage in the opposite polarity by using the negative bridge **251** as the bridge used to bring voltage to the lifting magnet **113** and returning energy to the AC input (for example, at the end of “Drop”). The time during which the negative bridge **251**

restores energy from the magnet back to the AC input is called the secondary discharge. Those skilled in the art will recognize that the polarity of the lifting magnet **113** is reversible, such that the positive bridge **250** can be used to demagnetize the lifting magnet **113** during the “Drop” mode and the negative bridge **251** can be used to magnetize the lifting magnet **113** during the “Lift” mode; the previous directions have been described for convenience. It will also be apparent to one skilled in the art that the use of three-phase power is not necessary for all cycles.

The thyristors **101-112** act as transient protection devices themselves, and prevent failures in the DC Regulated Power Supply **400** or in the AC input power from damaging components in the DC Regulated Power Supply **400** by conducting before the output voltage of the supply rises above the breakover voltage of the thyristors by freewheeling the magnet coil. The thyristors **101-112** are usually chosen so that their breakover voltage is higher than the greatest voltage expected to be experienced from the power source, so that they can be turned on by intentional voltage pulses applied to the gates. If other types of switches are used, those skilled in the art will recognize that transient protection devices can be added to protect against voltage spikes.

FIG. **3** shows the actual and equivalent circuits used for magnet resistance calculation. Overheating of the lifting magnet **113** can lead to melting or short-circuits, and a need to rewind the lifting magnet **113**. The internal temperature of the lifting magnet **113** can be measured by a thermistor or other temperature sensor, if such a device was embedded in the lifting magnet **113** during the process of magnet winding. In one embodiment, the temperature of the lifting magnet **113** is calculated by measuring the electrical resistance **301** of the magnet **113** because the resistance **301** of the lifting magnet **113** is substantially proportional to the temperature of the lifting magnet **113**. The magnet resistance **301** is calculated based on readings of voltage and current across the lifting magnet **113** or across the load side of the DC Regulated Power Supply **400** and by taking into account the resistance **302** of the cables. The resistance **302** of the cables can either be (1) calibrated out, (2) measured and subsequently subtracted from the total resistance reading, or (3) disregarded if the resistance **302** is assumed to be small in relation to the magnet resistance **301**. The cables are not expected to get hot because of the low value of their resistance **302** and their exposure to air. However, the lifting magnet **113** gets hot because of the relatively high density of windings in relation to the surface area available for cooling (typically, cooling is achieved by natural convection). Lifting magnets are generally designed for a resistance increase of about 50% when they get hot. The formula to calculate the magnet resistance **301** at a given temperature is: $R_H = R_0 (1 + K \Delta\theta)$, where R_0 = cold resistance of the lifting magnet **113**, in Ω , K = temperature coefficient of the magnet **113** (typically $0.004 \Omega/^\circ C$. for a copper- or aluminum-wound magnet), and $\Delta\theta$ = change in temperature, in $^\circ C$.

The lifting magnet’s calculated resistance **301** is compared to two parameters: the “Alarm resistance” and the “Trip resistance”. The “Alarm resistance” is a threshold value which, if exceeded, triggers the system to provide an alarm to warn the operator to either turn off the lifting magnet **113** or to indicate that the system is picking up materials which are too hot, or that the cable is partially cut, or that a connection is loose. The “Trip resistance” is a threshold value which, if exceeded, triggers the system to protect the lifting magnet **113** from overheating. When the trip resistance is exceeded, the system activates a trip relay. If the trip relay is activated when the system is in “Hold” mode, the system will continue through

the normal modes of operation of “Hold” and “Drop”. However, if the Trip relay is activated when the operator requests a “Lift”, the system will not enter into “Lift” mode and instead go directly to “Hold” mode.

FIG. 4A shows voltage and current during the “Lift”, “Hold” and “Drop” modes for applications such as scrap material handling. The “Lift” mode is initiated by the operator. During the “Lift” mode, the positive bridge 250 applies a relatively high voltage level across the lifting magnet 113 until the current reaches the limiting current for the lifting magnet 113 through the positive bridge 250. The “Lift” mode lasts long enough to charge the lifting magnet 113 yet is short enough to prevent overheating of the lifting magnet 113. The length of time for the “Lift” mode will vary based on the time constant of the lifting magnet 113, the desired current for the lifting magnet 113 and the voltage applied to the lifting magnet 113. During the charge, the first portion of the “Lift” mode, there is a relatively high average voltage applied to the lifting magnet 113 (typically adjusted around 500V for an AC supply of 460V AC) and the current rises relatively fast. Once the current has risen, then the current is limited and held at a plateau for a specified time to allow magnetic field to build up.

The “Hold” mode is initiated automatically after a specified time in “Lift” mode. During the “Hold” mode, the positive bridge 250 applies a different (lower) voltage level across the lifting magnet 113, for as long as the operator needs in order to move the load. The “Hold” voltage is set below the lifting magnet 113 rated voltage, and the lifting magnet 113 is thus expected to cool down somewhat during the “Hold” mode. In other words, for safety reasons, an energized lifting magnet 113, possibly carrying an overhead load, is not made to automatically shut down. Because of the reduced voltage level, in “Hold” mode, the current decreases to a second lower plateau. Under normal conditions, in the “Hold” mode, the load has already been attracted, air gaps are at a relatively low level, and therefore, less magnetic flux is required to keep the load attached. Therefore, the current and the magnetic field across the lifting magnet 113 can be reduced. At the end of the “Hold” mode, the firing angle of the thyristors phases back and energy from the lifting magnet 113 is returned to the AC input until current reaches zero.

The “Drop” mode is initiated by the operator and causes the “Lift” or “Hold” mode to terminate. During the “Drop” mode, the positive bridge 250 thyristors’ firing pulses get delayed to cause the polarity of voltage across the lifting magnet 113 to reverse. After the current from the “Drop” mode or the “Hold” mode reaches zero, the negative bridge 251 applies a voltage of reverse polarity across the lifting magnet 113, i.e. reverses the sense of voltage signal until the current reaches the current limit for the lifting magnet 113 through the negative bridge 251. The “Drop” mode expires after yet another specified time. During the “Drop” mode, the current value is specified such as to produce a magnetic field in the lifting magnet 113 that is of the same magnitude but in an opposite direction of the residual magnetic field across the lifting magnet 113, such that the two fields cancel each other. When the lifting magnet 113 is free of residual magnetic field, the load detaches freely from the lifting magnet 113.

In FIG. 4A, during phase 0, the lifting magnet 113 is idle. Phase 1 represents the “Lift” mode during voltage regulation, where the voltage can be adjusted to a relatively high value in order to magnetize the lifting magnet 113 relatively quickly. Phase 2 represents the “Lift” mode during current limiting, where the current limit can be adjusted close to the cold current rating for the lifting magnet 113. Phase 3 represents the “Hold” mode, during which the current is adjusted to be a portion of the cold current such that the lifting magnet 113

does not warm up, while still holding the load; the magnitude of the current during the “Hold” mode can be adjusted such as to compensate for the amount of magnetic hysteresis. Phase 4 represents the “Drop” mode during transient, where the current is adjusted to compensate for the magnetic hysteresis. Phase 5 represents the “Drop” mode, where both current and voltage are held constant, in order to match the magnetic time constant of the lifting magnet 113.

FIG. 4B shows voltage and current during the “Lift”, “Hold” and “Drop” modes for applications such as handling of slab or plates material. The “Lift” mode is initiated by the operator. During the “Lift” mode, the positive bridge 250 applies a preset voltage level across the lifting magnet 113. The length of time for the “Lift” mode will vary based on the time constant of the lifting magnet 113. During the charge, the slab or plates attach to the lifting magnet 113. After the charge, the operator starts to hoist the lifting magnet 113 for a few feet. If the operator wishes to hoist the load further, then the operator can apply a relatively higher voltage to the lifting magnet 113 during the “Hold” mode in order to maintain the load attached to the lifting magnet 113. The “Drop” mode operates the same for this slab or plates’ material application as it does for the scrap materials handling application.

In FIG. 4B, during phase 0, the lifting magnet 113 is idle. Phase 1 represents the “Lift” mode where a preset voltage is applied to the lifting magnet 113. Phase 2 represents the “Hold” mode, during which the operator selects a relatively higher voltage to apply across the lifting magnet 113. Phase 4 represents the “Drop” mode during transient, where the current is adjusted to compensate for the magnetic hysteresis. Phase 5 represents the “Drop” mode, where both current and voltage are held relatively constant, in order to match the magnetic time constant of the lifting magnet 113.

In addition to the above three modes, there is a “Sweep” mode, which is optionally activated by the operator. The “Sweep” mode is for applications where the rail car or container to be unloaded has its bottom or walls formed of magnetic material. When unloading is almost complete, to prevent the lifting magnet 113 from sticking to the bottom or walls of the rail car or container, a “Sweep” switch can be activated by the operator to reduce the “Lift” and “Hold” voltages. The reduced voltage across the lifting magnet 113 prevents the magnetized load from attaching to the bottom or walls of the rail car or container while the lifting magnet 113 is unloading.

In one embodiment, the “Lift”, “Hold”, “Drop” and “Sweep” modes of the magnet controller circuit described above, used to control the lifting magnet 113, can be controlled through the use of the Logic Controller (LC) 100.

The logical programming of the LC 100 is represented in sequential function charts (SFC). SFC is a graphical programming language used for logical controllers, defined in IEC 848. SFC can be used to program processes that can be split into steps.

FIG. 5 shows a general SFC. Main components of SFC are: steps with associated actions, transitions with an associated logic condition or associated logic conditions, and directed links between steps and transitions. Steps can be active or inactive. Actions are executed for active steps. A step can be active for one of two motives: (1) the step is an initial step as specified by the programmer, (2) the step was activated during a scan cycle and was not deactivated since. A step is activated when the steps above that step are active and the connecting transition’s associated condition is true. When a transition is passed, the steps above the transition are deactivated at once and the steps below the transition are activated at once.

An SFC program has three parts: (1) preprocessing, which includes power returns, faults, changes of operating mode, pre-positioning of SFC steps, input logic; (2) sequential processing, which includes steps, actions associated with steps, transitions and transition conditions; and (3) post-processing, which includes commands from the sequential processing for controlling the outputs and safety interlocks specific to the outputs.

FIG. 6 shows a flowchart for the Main SFC. In FIG. 6, step "10 Main" has no associated actions and the transition to step "20 Ready" is true. Step "10 Main" can be accessed either if a "Drop" input is received by the operator while in step "20 Ready" or when the SFC is initialized. Step "20 Ready" is initiated either automatically after step "10 Main" or after a preset time TM2 in step "50 Drop". Step "20 Ready" starts the Ready SFC. From step "20 Ready", a "Drop" command by the operator calls step 10. Step "30 Lift" starts the Lift SFC. "Lift" is initiated by a lift command from steps "20 Ready" or "50 Drop". Step "40 Hold" is initiated either automatically after a preset time TM1 in step "30 Lift", or immediately after a "Lift" input in step "20 Ready" if the magnet temperature trip relay is active. Step "40 Hold" initiates the Hold SFC. Step "50 Drop" is initiated by a "Drop" rising edge from either step "30 Lift" or "40 Hold", and step "50 Drop" initiates the Drop SFC.

FIG. 7 shows a flow chart for the Ready SFC. Step "21 Ready" is the initialization step. Step "21 Ready" will be active when the Main SFC is not in step "20 Ready". Step "21 Ready" is not associated with any actions. Step "20 Ready" getting active in the Main SFC causes transition X20 to be true and to make step "22 Run Off" active. Once step "20 Ready" is active, unless step "20 Ready" stops to be active and causes X20 to be true and the SFC to return to step "21 Ready", the SFC stays in step "22 Run Off". While the SFC is in step "22 Run Off", the LC 100 sends commands to the control circuitry to turn off the current in the magnet 113. From step "22 Run Off", the SFC transitions to step "23 Voltage Selection 1 Off" when the Send Command Done is true, and the SFC transitions from step "23 Voltage Selection 1 Off" to step "24 Negative Bridge Off" when the Send Command Done is true. From step "24 Negative Bridge Off", the SFC transitions to step "27 Done" when the Send Command Done is true.

FIG. 8 shows a flowchart for the Lift SFC. The first step to be activated, "32 Run On", is to reduce to a minimum the delay time between the activation of the "Lift" input by the operator and the response by the circuitry. Steps "35 Negative Bridge Off" and "36 Voltage Selection 1 Off" are used if the step before "30 Lift" was "50 Drop" in the Main SFC and the Send Command Done is true. "Sweep" is a switch that can be toggled by the operator. If "Sweep" is on, "Voltage Selection 2" and "Current Limit Selection 2" are on, and the system selects the second set of voltage references and the second current limit. If "Sweep" is off, "Voltage Selection 2" and "Current Limit Selection 2" are off, and the system selects the primary set of voltage references and the primary current limit.

FIG. 9 shows a flow chart for the Hold SFC. Step "41 Hold" is the initialization step. Step "40 Hold" getting active in the Main SFC causes transition X40 to be true and to make step "42 Voltage Selection 1 On" active. Once the step "42 Voltage Selection 1 On" is active, unless step "40 Hold" stops to be active and causes X40 to be true and the SFC to return to step "41 Hold", the SFC stays in step "42 Voltage Selection 1 On". While the SFC is in step "42 Voltage Selection 1 On", the LC 100 sends commands to control the lifting magnet circuitry.

The SFC transitions from step "42 Voltage Selection 1 On" to step "49 Run On" when Send Command Done is true. The SFC transitions from step "49 Run On" to step "90 Negative Bridge Off" when Send Command Done is true. The SFC transitions from step "90 Negative Bridge Off" to step "43 Ready" when Send Command Done is true. Once the SFC is in step "43 Ready", after the timer TM3 elapses, the voltage and current across the lifting magnet 113 are stabilized and the LC 100 gets updates from the system for readings of Volts across the lifting magnet 113 and Amps going across the lifting magnet 113. Based on those readings, the LC 100 calculates the magnet resistance and determines whether or not the alarm resistance is exceeded, and whether or not the trip resistance is exceeded. Each of these updates is requested after the previous update is done.

FIG. 10 shows a flow chart for the Drop SFC. Step "50 Drop" getting active in the Main SFC causes transition X50 to be true and to make step "52 Negative Bridge On" active. In step "52 Negative Bridge On", the system selects the negative bridge 251. The current limit for the negative bridge 251 is set at a fraction of the current limit for the positive bridge 250. Then, in step "55 Voltage Selection 1 Off", voltage selection is reset. The system remains in "Drop" mode until the Main SFC exits step "50 Drop" either after timer TM2 expires or when a "Lift" command is requested by the operator.

In one embodiment, the circuitry used to control the lifting magnet 113 can be obtained by appropriately programming a DC Regulated Power Supply 400, normally used to control motors. The LC 100 can be set up with access to the DC Regulated Power Supply 400 logic, allowing the setting of parameters to be changed to suit different operating conditions.

In one embodiment, the the Mentor II DC Drive manufactured by Control Techniques of Minnesota, United States can be used as the DC Regulated Power Supply.

The thyristors in the DC Regulated Power Supply 400 are fired when the "Run ON" command is sent during step "32 Run On" of the Lift SFC.

During the "Lift" mode, the positive bridge 250 applies the voltage from the DC Regulated Power Supply 400, usually set around 500V DC across a 240V DC rated lifting magnet 113 to boost the charge until the current gets limited by the limiting current for the lifting magnet 113. In addition, the "Lift" time is controlled by the value in timer TM1 of the LC 100.

During the "Hold" mode, the positive bridge 250 applies a voltage of around 180 V DC across a 240 V DC rated magnet 113. This holding voltage is adjustable and set in the LC 100. In addition, after being in "Hold" mode for about 5 seconds, as preset in timer TM3 of the LC 100, and periodically at each period of time preset in timer TM3, the LC 100 reads the current and voltage across the DC Regulated Power Supply 400.

During the "Drop" mode, the negative bridge 251 is turned on by changing the value in parameter "Bridge Selector", shown in FIG. 11. During the "Drop" mode, the current can be limited by the parameter "Current Limit for Negative Bridge" shown in FIG. 12. In addition, the time for the "Drop" mode is preset by parameter TM2.

During the "Sweep" mode, depending on whether a "Sweep" command is received by the operator at the LC 100, "Voltage Selection 2" is set to on or off in the DC Regulated Power Supply 400. If "Sweep" is off, "Voltage Selection 2" is off, as shown in FIG. 11. Therefore, the reference voltages in "Voltage Reference 1" and "Voltage Reference 2" of the DC Regulated Power Supply 400 are respectively selected during "Lift" and "Drop", depending on the value of "Voltage Selection 1". On the other hand, if "Sweep" is on, "Voltage Selection 1" is on, and the system selects the second set of voltage references and the second current limit.

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tion 2” is enabled. By enabling “Voltage Selection 2”, the “Voltage Reference 3” and “Voltage Reference 4” of the DC Regulated Power Supply 400 are respectively selected during “Lift” and “Drop”, again, depending on the value of “Voltage Selection 1”. Furthermore, during the “Sweep” mode, the current is limited by parameter “Current Limit 2”, as shown in FIG. 12.

It will be apparent to those skilled in the art how the “Lift” and “Hold” modes described above function when the system is used in a slab or plates material handling application, and the voltage levels are adjusted accordingly.

The temperature protection for the lifting magnet 113 is controlled through the use of parameters “Alarm Resistance” and “Trip Resistance”. The resistance value at which the system activates an alarm relay during the “Hold” mode is set into parameter “Alarm Resistance”, based on the lifting magnet 113 manufacturer’s rated hot current. The resistance value at which the system activates a trip relay is set into parameter “Trip Resistance”, based on the insulation class temperature of the lifting magnet 113. When the resistance 301 of the lifting magnet 113 exceeds the value set in parameter “Trip Resistance”, the next cycle begins directly in “Hold” mode. When the lifting magnet 113 cools down and its resistance value 301 becomes less than the value set in parameter “Trip Resistance”, then the system enters “Lift” mode again. Cable ohmic resistance 302 of the wiring between the lifting magnet 113 and the LC 100 is set in parameter “Wiring Resistance”. To calculate the magnet resistance, the LC 100 divides the voltage by the current and then subtracts the value set in “Wiring resistance”.

In addition to the above parameter settings, some parameters in selected DC Regulated Power Supplies can be adjusted to accommodate for highly inductive loads like the lifting magnet 113. Generally, voltage loop and current loop PID gain circuitries need to be optimized, current feedback resistors scaled to accommodate for the inductance of the magnet 113, and a safety margin of 1 supply cycle added to the bridge changeover logic to prevent shorting the line by having a thyristor in one bridge firing while another thyristor in the other bridge were still conducting.

FIG. 13 shows a communication setup page 1300 for display on the operator console 260 for user control of the lifting magnet system. The communication setup page 1300 includes a communication selection control to allow the user to select the communication system (e.g., Ethernet, serial bus, etc.) used for communication between the operator console 260 and the control system 100. Depending on the type of communication system chosen, the user can also specify various communication parameters such as, for example, port number, bit rate, drive address, polling interval, IP address, transmission timeout, etc. FIG. 14 shows a first parameter setup page 1400 for display on the operator console 260 for user control of the lifting magnet system. The page 1400 includes dialog controls to allow the user to specify the operating parameters listed in Table 1.

TABLE 1

Parameter ID	Description	Units
15.18	Cold Current	Amps
15.06	Normal mode: Lift Voltage (e.g., the voltage during phase 1 described in connection with in FIG. 4A)	Volts
15.07	Normal mode: Lift Current Limit (e.g., the current during phase 2 described in connection with in FIG. 4A)	Amps

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TABLE 1-continued

Parameter ID	Description	Units
5 15.08	Normal mode: Economy Voltage (e.g., the voltage during phase 3 described in connection with in FIG. 4A)	Volts
15.09	Normal mode: Drop Voltage (e.g., the voltage during phase 4 described in connection with in FIG. 4A)	Volts
10 15.10	Normal mode: Drop Current Limit (e.g., the current during phase 5 described in connection with in FIG. 4A)	Amps
15.11	Normal mode: Lift “Pick” Time (e.g., the time corresponding to the combination of phase 1 and phase 2 in FIG. 4A)	Seconds
15 15.12	Normal mode: Drop “Clean” Time (e.g., the time corresponding to the combination of phase 4 and phase 5 in described in connection with in FIG. 4A)	Seconds
16.06	Sweep mode: Lift Voltage (e.g., the voltage during phase 1 described in connection with in FIG. 4B)	Volts
16.07	Sweep mode: Lift Current Limit (e.g., the current during phase 2 described in connection with in FIG. 4B)	Amps
20 16.08	Sweep mode: Economy Voltage (e.g., the voltage during phase 3 described in connection with in FIG. 4B)	Volts
16.09	Sweep mode: Drop Voltage (e.g., the voltage during phase 4 described in connection with in FIG. 4B)	Volts
25 16.10	Sweep mode: Drop Current Limit (e.g., the current during phase 5 described in connection with in FIG. 4B)	Amps
16.11	Sweep mode: Lift “Pick” Time (e.g., the combined time of phase 1 and phase 2 described in connection with in FIG. 4A)	Seconds
30 16.12	Sweep mode: Drop “Clean” Time (e.g., the combined time of phase 4 and phase 5 in FIG. 4B.)	Seconds
07.08	Resistance alarm set point	Ohms
07.09	Resistance Trip set point	Ohms
07.10	Cable Resistance (e.g., the resistance 302 shown in FIG. 3.)	Ohms

FIG. 15 shows a second parameter setup page 1500 for display on the operator console 260 for user control of the lifting magnet system. The parameter page 1500 allows the user to specify parameters corresponding to dribble/plate options wherein multiple objects (e.g., steel plates) are dropped in sequence. The page 1500 includes a dialog control to allow the user to specify a Parameter 15.14 that specified a dribble mode. Other dialog controls allow the user to specify Parameters 15.08, 15.29, 15.16-15.20, 16.01, and 16.16-16.21. The dribble modes can include one or more of the following 6 modes:

1. Dribble Disabled.
2. Press and Release of the Dribble button causes the magnet voltage to ramp down to zero at a rate specified by the Parameter 15.16 (volts/second). Pressing the DROP button overrides and inverts this function.
3. Press and hold of the Dribble button begins the ramp to zero. Releasing the Dribble button stops the ramp and holds at the present voltage level. Press and hold the Dribble button again causes the voltage to continue to ramp down from current voltage level. Pressing the DROP button overrides and inverts this function.
4. Press and release of the Dribble button begins a ramp to zero. The next press and release of the Dribble button stops the ramp and holds at current voltage level. The next press and release of the Dribble button continues the ramp from the current voltage level. Future presses and releases cycle the ramp on and off. Pressing the DROP button overrides and inverts this function.
5. Press and hold of the PLATE button begins a ramp to zero. Release of the PLATE button stops the ramp, saves

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the current voltage value, and increases hold voltage by a preset value specified by the Parameter 15.19 (e.g., 0V to 100V). The increased hold voltage does not exceed original voltage setting. Press and hold the PLATE button again to continue the ramp from the saved voltage level. Pressing the DROP button overrides and inverts this function.

6. Press and Release of the PLATE button begins a ramp to zero. A subsequent press and release of the PLATE button stops the ramp, saves the current voltage value, and increases the hold voltage by a preset value specified by the Parameter 15.19. Increased hold voltage does not exceed the original voltage setting. Future presses of the PLATE button cycle the ramp on and off from the saved voltage levels. Pressing the DROP button overrides and inverts this function.
7. Press and Release of the Plate button drops the voltage to a first preset voltage level specified by a Parameter 16.16. After a time delay specified by a Parameter 15.20 (e.g., 0 to 25.5 seconds) the voltage is raised by a preset value specified by the Parameter 15.19. The increased hold voltage does not exceed the original voltage setting. Second press and release drops voltage to second preset voltage level specified by a Parameter 16.17. The time delay is again applied and then the voltage is raised to the increased hold voltage. Further presses of the PLATE button drop the voltage to third, fourth, and fifth preset voltage levels specified by Parameters 16.18, 16.19, and 16.20, respectively. Pressing the DROP button overrides and inverts this function.

In one embodiment, the dribble/plate modes 4, 5, and/or 6 are stopped and the system returns to full hold voltage when the bridge/trolley Parameter 16.21 is set true (e.g., a user dialog checkbox corresponding to the Parameter 16.21 is checked) and the bridge **190** or trolley **191** moves.

Although the dribble/plate modes are normally used during drop, in one embodiment, the dribble/plate modes can be used in lift to allow an operator to pick up a desired number of plates or objects.

Using a checkbox corresponding to Parameter 15.29, the user can instruct the system to use an adjusted lift voltage where the lift voltage is set using a potentiometer or other user control corresponding to Parameter 15.08. The economy hold voltage (e.g., the voltage used during phase 3 of FIGS. 4A and 4B) is specified by the Parameter 15.08.

FIG. 16 shows a monitor page **1600** for display on the operator console **260** for user control of the lifting magnet system. The monitor page **1600** displays various status and diagnostic values parameters such as, output voltage to the magnet (Parameter 03.04), output current to the magnet (Parameter 05.02), input voltage (Parameter 07.06), magnet resistance (Parameter 03.14). The monitor page also indicates the off/on status of various modes and settings, such as: run mode, lift mode, drop mode, sweep mode, bridge/trolley override, dribble/plate mode, enable. The monitor page includes a trip indicator and display showing a trip code **1610**.

In one embodiment, the trip codes **1610** include one or more of the following conditions: Hardware Fault, Phase Sequence error, External Trip, External Power Supply error, Current (Control) Loop Open Circuit, Serial Communications Link (Interface) Loss, Field Overcurrent, Magnet Overheat, Field On, Feedback Reversal, Field Loss, Feedback Loss, Power Supply Loss, Overcurrent. Current * Time Trip (e.g., current * time has exceeded the defined threshold), Thermistor Overheat (Thermal Switch), EEprom Failure, Software Error, RS485 Trip, and/or Communication Error.

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FIG. 17 shows an operations page **1700** for display on the operator console **260** for user control of the lifting magnet system. The operations page **1700** includes dialog displays to show the following: total number of operations, total time of magnet operation, total power-up time. For normal mode, the operations page **1700** includes dialog displays to show: number of operations, lift time, economy time (e.g., phase 3 time), and drop time. For sweep mode, the operations page **1700** includes dialog displays to show: number of operations, lift time, economy time (e.g., phase 3 time), and drop time. The operations page **1700** includes dialog buttons to allow the user to reset the operations counters, operation times, and power-up timer.

FIG. 18 shows an energy computation page **1800** for display on the operator console **260** for user control of the lifting magnet system **100**. The energy page **1800** includes dialog displays to allow the user to compare energy usage of the magnet controller **100** with energy usage of a prior system and thereby allow the user to assess the energy cost savings of the magnet controller **100**. The energy page **1800** includes dialog controls to allow the user to specify the parameters of the prior system. These prior system parameters include: normal mode lift voltage, normal mode hold voltage, normal mode drop voltage, normal mode lift time, normal mode drop time, normal mode dropping resistor value, sweep mode lift voltage, sweep mode hold voltage, sweep mode economy time, sweep mode lift time, and sweep mode drop time. The energy computation page **1800** also includes a dialog control **1801** to allow the user to specify the cost of energy.

The energy computation page **1800** includes dialog displays to show energy computations, including: energy usage by the controller **100**, calculated energy usage if the prior system had been used instead of the controller **100**, energy savings of the controller **100** in kWhr, energy savings of the controller **100** in dollars.

FIG. 19 shows a parameter diagram **1900** for display on the operator console **260** for user control of the lifting magnet system. In one embodiment, the parameter diagram **1900** corresponds to the voltage and current diagram in FIG. 4A with corresponding labels for the normal mode parameters 15.06-15.12 discussed in connection with the setup page **1400** of FIG. 14. In one embodiment, the parameter diagram **1900** corresponds to the voltage and current diagram in FIG. 4B with corresponding labels for the sweep mode parameters 16.06-16.12 discussed in connection with the setup page **1400** of FIG. 14. In one embodiment, the user can select between diagrams corresponding to normal mode and sweep mode.

In one embodiment, the user console provides three levels of security. In one embodiment, the different levels are password protected. In one embodiment, the levels are protected using different passwords. A first security level (Level 0) provides only read-only access. A second security level (Level 1) provides read/write access to the various parameters except for the parameters on the energy page **1800**. A third security level (Level 2) provides read/write access to all parameters.

It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrated embodiments and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributed thereof; furthermore, various omissions, substitutions and changes may be made without departing from the spirit of the inventions. The foregoing description of the embodiments is, therefore, to be considered in all respects

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as illustrative and not restrictive, with the scope of the invention being delineated by the appended claims and their equivalents.

What is claimed is:

1. A lifting magnet system, comprising:
 a three-phase AC power source;
 a positive bridge circuit comprising six thyristors, wherein
 a first pair of thyristors are arranged in series with a first
 phase of said three-phase AC power source, a second
 pair of thyristors are arranged in series with a second
 phase of said three-phase AC power source, and a third
 pair of thyristors are arranged in series with a third phase
 of said three-phase AC power source wherein during lift,
 said positive bridge circuit is configured to generate a
 first voltage, and during hold, said positive bridge circuit
 is configured to generate a second voltage less than said
 first voltage, in a sweep mode, said positive bridge circuit
 is configured to generate a third voltage during
 sweep lift that is less than said first voltage and a fourth
 voltage during sweep hold that is less than said second
 voltage;
 a negative bridge circuit comprising six thyristors, wherein
 a fourth pair of thyristors are arranged in series with said
 first phase of said three-phase AC power source, a fifth
 pair of thyristors are arranged in series with said second
 phase of said three-phase AC power source, and a sixth
 pair of thyristors are arranged in series with a third phase
 of said three-phase AC power source,
 wherein said first pair of thyristors of said positive bridge
 circuit are arranged in parallel with said fourth pair of
 thyristors of said negative bridge circuit, said second
 pair of thyristors of said positive bridge circuit are
 arranged in parallel with said fifth pair of thyristors of
 said negative bridge circuit, and said third pair of thyris-
 tors of said positive bridge circuit are arranged in paral-
 lel with said sixth pair of thyristors of said negative
 bridge circuit;
 an electromagnet;
 a logic controller controlling said positive bridge circuit
 and said negative bridge circuit, during lift said logic
 controller controlling the thyristors in the positive bridge
 circuit in repeating sequence to output substantially
 direct current to the electromagnet and to apply said first
 voltage to the electromagnet to charge the electromagnet
 rapidly, during hold said logic controller controlling the
 thyristors in the positive bridge circuit in repeating
 sequence to output substantially direct current to the
 electromagnet and to apply said second voltage to the
 electromagnet that is less than the first voltage applied
 during lift in order to prevent damage to the electromag-
 net,
 during sweep lift said logic controller controlling said thy-
 ristors in said positive bridge circuit in repeating
 sequence to apply said third voltage to said electromag-
 net that is less than said first voltage,
 during sweep hold said logic controller further controlling
 said thyristors to apply a fourth voltage to said electro-
 magnet that is less than said second voltage,
 during drop said logic controller controlling the thyristors
 in the negative bridge circuit in repeating sequence to
 output substantially direct current to the electromagnet
 and to apply a voltage to the electromagnet that is the
 reverse of the voltage applied during lift to demagnetize
 the electromagnet; and
 a user console to allow a user to specify said sweep mode
 applied during lift.

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2. The lifting magnet system of claim 1, wherein said
 thyristors prevent damage to themselves by automatically
 conducting before the voltage across the electromagnet rises
 above the breakover voltage of said thyristors.

3. The lifting magnet system of claim 1, wherein the brea-
 kover voltage of said thyristors is higher than the greatest
 voltage expected to be experienced from the power source.

4. The lifting magnet system of claim 1, wherein said
 console allows said user to select a dribble/plate mode.

5. The lifting magnet system of claim 1, wherein said
 console allows said user to select a dribble ramp rate.

6. The lifting magnet system of claim 1, wherein said
 console displays energy saved by the lifting magnet system.

7. The lifting magnet system of claim 1, wherein a user can
 specify stepped voltages for use in a dribble mode.

8. A control system for lifting magnet, comprising:

a first bridge comprising a plurality of switches wherein
 said plurality of switches in said first bridge comprise at
 least a first serial pair of switches configured to transmit
 current in a first direction wherein during lift, said first
 bridge is configured to generate a first voltage, and dur-
 ing hold, said first bridge is configured to generate a
 second voltage less than said first voltage, in a sweep
 mode, said first bridge circuit is configured to generate a
 third voltage during sweep lift that is less than said first
 voltage and a fourth voltage during sweep hold that is
 less than said second voltage;

a second bridge comprising a plurality of switches wherein
 said plurality of switches in said second bridge comprise
 at least a second serial pair of switches configured to
 transmit current in a second direction, wherein the first
 and second serial pairs of switches are further arranged
 in parallel; and

a logic controller controlling said first bridge and said
 second bridge, during lift said logic controller control-
 ling the switches in the first bridge in repeating sequence
 to output substantially direct current to the lifting mag-
 net and to apply the first voltage to the lifting magnet to
 charge the lifting magnet,

during hold said logic controller controlling the switches in
 the first bridge in repeating sequence to output substan-
 tially direct current to the lifting magnet and to apply the
 second voltage to the lifting magnet lower than the first
 voltage applied during lift to prevent damage to the
 lifting magnet,

during sweep lift, said logic controller controlling said
 switches in said first bridge in repeating sequence to
 apply said third voltage to said lifting magnet that is less
 than said first voltage,

during sweep hold, said logic controller further controlling
 said switch to apply a fourth voltage to said lifting mag-
 net that is less than said second voltage,

during drop said logic controller controlling the switches in
 the second bridge in repeating sequence to output substan-
 tially direct current to the lifting magnet and to apply
 a voltage to the lifting magnet that is the reverse of the
 first voltage applied during lift to demagnetize the lifting
 magnet wherein a user specifies one or more operating
 parameters for a normal mode, one or more operating
 parameters for the sweep mode, and where the user can
 select from a plurality of dribble/plate modes.

9. The control system of claim 8, wherein said switches
 comprise thyristors.

10. The control system of claim 8, wherein said switches
 are turned on before the voltage across the lifting magnet rises
 above the drain-source voltage of said switches.

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11. The control system of claim 8 where the voltage applied during lift is different than the voltage applied during hold.

12. The control system of claim 8 where the voltage applied during lift is greater than the voltage applied during hold.

13. The control system of claim 8 where the voltage applied during lift is less than the voltage applied during hold.

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14. The control system of claim 8 where the voltage applied during lift is at least twice the voltage applied during hold.

15. The control system of claim 8 where the voltage applied during lift and the voltage applied during hold are user-selectable.

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